W72-08825

CLEAN WATER

WATER POLLUTION CONTROL RESEARCH SERIES • 16050 DEX 07/70

PB 209 641

SEWAGE ODOR CONTROL BY LIQUID-GAS EXTRACTION

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

U. S. DEPARTMENT OF THE INTERIOR • FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM	W72-08825

SEWAGE ODOR CONTROL BY LIQUID-GAS EXTRACTION,

FWPCA Program
16050 DEX 07/70

San Diego Water Utilities Department, California

Grant WPD 135-01-67

Research Series, July, 1970, 114 p, 39 fig, 31 tab, 24 ref.

Water Pollution Control

An investigation into chemical methods for treatment of foul air was conducted by the City of San Diego. A pilot liquid-gas contactor was constructed of PVC lining and stainless steel shafting. Several oxidizing and adsorptive chemicals (tap water, sodium hydroxide, calcium hypochlorite, potassium permanganate, copper sulfate, copper chelate, etc.) as well as biologically active materials, were used in the contractor to remove the foul odors in air vented from the sewage sedimentation tanks. Under the experimental sulfide levels of 1.0 to 20.0 ppm H_2S (by weight in the gas) good removal was shown by commercial sodium hydroxide, gaseous chlorine and ammoniated copper chelate. Ozone, when used in conjunction with other reactive chemicals, helped in removal of odors other than H_2S, as well as H_2S. Sodium hydroxide (caustic soda) foamed excessively and would require continuous monitoring and automated feed control. Approximate costs (chemicals only) for treating 1,000,000 cubic feet (28,318.5 cubic meters) of foul air range from $0.18 to $46.00 depending on sulfide concentration and chemical used.

*Odor, *Separation techniques, *Sewage effluents, California, Pilot plants, Air pollution, Waste treatment, Gases, Air-water interfaces, Hydrogen sulfide, Costs, Pollution abatement

*San Diego (Calif), *Liquid-gas extraction, *Sewage odor control, Treatment costs

Ø5D, Ø5G

Available from the National Technical Information Service as PB 209 641 $3.00 in paper copy, $0.65 in microfiche		Send To: WATER RESOURCES SCIENTIFIC INFORMATION CENTER U.S. DEPARTMENT OF THE INTERIOR WASHINGTON, D.C. 20240

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Reports describe the results and progress in the control and abatement of pollution of our Nation's waters. They provide a central source of information on the research, development, and demonstration activities of the Federal Water Pollution Control Administration, Department of the Interior, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Water Pollution Control Research Reports will be distributed to requesters as supplies permit. Requests should be sent to the Planning and Resources Office, Office of Research and Development, Federal Water Pollution Control Administration, Department of the Interior, Washington, D. C. 20242.

SEWAGE ODOR CONTROL

BY LIQUID-GAS EXTRACTION

A Report of a Research Project to study the feasibility of Sewage Odor Control by liquid-gas extraction through the use of a two phase contactor and absorbing solutions.

by

WATER UTILITIES DEPARTMENT

CITY OF SAN DIEGO, CALIFORNIA

Work conducted by the City of San Diego and jointly funded with the Office of Research and Development, Federal Water Pollution Control Administration, U.S. Department of The Interior.

for the

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

DEPARTMENT OF THE INTERIOR

Demonstration Grant No. W.P.D. 135-01-67

Contract No. 16050DEX

July, 1970

CITY OF SAN DIEGO

CITY OFFICIALS

MAYOR

Frank Curran

COUNCILMEN

Helen Cobb

Henry L. Landt

Floyd L. Morrow

Allen Hitch

Sam T. Loftin

Leon Williams

Bob Martinet

Mike Schaefer

CITY MANAGER

Walter Hahn, Jr.

ASSISTANT CITY MANAGER

Kimball Moore

DIRECTOR OF FACILITIES

Ralph E. Graham

WATER UTILITIES DEPARTMENT

Roy E. Dodson, Jr. - DIRECTOR

Ernest E. Clay - ASSISTANT DIRECTOR

PROJECT STAFF

PROJECT DIRECTOR	Leland Cook, Jr. Water Utilities Superintendent
PROJECT CO-DIRECTOR	Jack H. Kuhns Assistant Sanitary Engineer
CONSULTING RESEARCH CHEMIST	Donald A. Hoffman Laboratory Superintendent
MECHANICAL ENGINEER	Frederick E. Meyer Assistant Mechanical Engineer
SENIOR CHEMIST IN CHARGE OF INVESTIGATION	William M. Conn Senior Chemist
ANALYSTS	William H. Sprague Associate Chemist
	Edward R. May Associate Chemist

TABLE OF CONTENTS

Section		Page
	Abstract.....	
	List of Figures.....	
	List of Tables.....	
1.....	Introduction.....	1
	Project Objectives.....	1
	Description.....	2
	Plan of Operation.....	2
	Available Facilities.....	2
2.....	Summary and Conclusions.....	8
3.....	Recommendations.....	11
4.....	Design of the Two Phase Contactor.....	12
5.....	Construction and Experimental Fabrication (of the Two Phase Contactor).....	13
	Testing of Adhesives for PVC (Polyvinyl Chloride) Fabrication.....	13
	Test Results.....	15
	Drilling of 41" O.D. PVC Discs.....	15
	Specifications of the Two Phase Contactor as constructed.....	17
6.....	Operational and Evaluation Phase (of the Two Phase Contactor).....	24
	Determination of Air Flow and calibration of Liquid Levels in holding Tank and Contactor.....	24
	Total Contact Area per minute.....	24
	Working Volumes.....	27
	H.P. Requirements at Given Disc R.P.M. and 15 Gal. Volume in Contactor.....	27

TABLE OF CONTENTS (Continued)

Location and Flow Arrangements..... 30

Construction Modification..... 30

Determination of Oxygen Mass Transfer Rate..... 30

7.....Discussion. Background of Study Methods..... 35

Details of Runs..... 38

Tap Water and pH Adjusted Tap Water..... 39

Caustic Soda (Technical Sodium Hydroxide)..... 50

Calcium Hypochlorite..... 53

Potassium Permanganate..... 58

Activated Sludge..... 62

Chelated Iron - Ammonium Complex..... 64

Raw Sewage..... 66

Ozone..... 67

Ozone Chambers..... 67

Experimental Conditions..... 72

Addenda - Ozone Lamps..... 76

Citric Acid, Ammonium Citrate, Citric Acid - Copper Sulfate Mixture..... 77

Citric Acid..... 77

Ammonium Citrate..... 77

Citric Acid - Copper Sulfate Mixture, Including Copper and Ammonium Complex at High pH Values..... 77

Acetic Acid, Alone and Buffered with Ammonia Gas..... 77

TABLE OF CONTENTS (Continued)

Cobalt Sulfate Solution in Tap Water..... 81

Ammonium Hydroxide and Ammonium Acetate Solutions in Tap Water. Copper Sulfate Added Later..... 81

Copper Chelate Solution in Tap Water.... 83

Copper Sulfate and Ammonia Gas Injection into Foul Air..... 83

Copper Sulfate and Chlorine Gas Injection Ahead of Contactor..... 90

Copper Sulfate, Chlorine & Ammonia Gas.. 90

Copper-Ammonium Complex, Chlorine & Ammonia Gas Injection..... 96

Morpholine and M-Pyrol..... 96

Ammonia Gas..... 100

Chlorine Gas..... 100

8.....Acknowledgements..... 109

9.....Bibliography..... 110

10.....Glossary..... 112

LIST OF FIGURES

Page

Fig. # 1...Two Phase Contactor Assembly..... 3

Fig. # 2...Two Phase Contactor. Isometric..... 4

Fig. # 3...Flow Diagram Schematic. Two Phase Contactor..... 5

Fig. # 4...Point Loma Plant. Main Process and Ventilation Schematic. Plate #3, Koebig and Koebig Study, 1969..... 7

Fig. # 5...Sides and Bottom of Two-Phase Contactor..... 16

Fig. # 6...Perforated PVC Discs and Stainless Steel Shaft of Two Phase Contactor..... 18

Fig. # 7..."Vari-Drive" assembly of Two Phase Contactor..... 19

Fig. # 8...View of PVC Ducts, Tank and Two Phase Contactor..... 22

Fig. # 9...View of PVC Ducts, Tank and Two Phase Contactor..... 23

Fig. #10...10-Point Transverse: mm Water Pressure Versus Velocity, Volume of Air..... 25

Fig. #11...Residence Time Versus Air Flow..... 26

Fig. #12...R.P.M. Disc Speed Given by Vari-Drive Settings..... 28

Fig. #13...Oxygen Transfer..... 33

Fig. #14...Oxygen Transfer..... 34

Fig. #15...A.I.S.I. Hydrogen Sulfide Sampler and Recorder..... 36

Fig. #16...H_2S Removal with Tap Water. 100 CFM, 200 CFM, 400 CFM Foul Air. 45

LIST OF FIGURES (Continued)

Fig. #17...H_2S Removal with pH adjusted Tap Water. 200 CFM Foul Air..... 47

Fig. #18...H_2S Removal with pH Adjusted Tap Water. 400 CFM Foul Air..... 48

Fig. #19...H_2S Removal with pH adjusted Tap Water. 600 CFM Foul Air..... 49

Fig. #20...H_2S Removal with 0.1% to 1.0% Caustic Soda (Sodium Hydroxide)..... 52

Fig. #21...H_2S Removal with Calcium Hypochlorite at input of 3.3 - 8.8 PPM H_2S..... 55

Fig. #22...H_2S Removal with 10,000; 15,000; 20,000 PPM Available Chlorine from Calcium Hypochlorite..... 57

Fig. #23...H_2S Removal with Potassium Permanganate at 2.8 - 10.8 PPM H_2S..... 60

Fig. #24...H_2S Removal with 1.0%, 2.0%, 5.0%, 10.0% Potassium Permanganate..... 61

Fig. #25...Ozone Chamber #1 (May 1969 - July 1969)..... 68

Fig. #26...Ozone Chamber #2 (August 1969 - October 1969)..... 69

Fig. #27...Ozone Chamber #3 (November 1969 - June 1970)..... 70

Fig. #28...View of Ozone Chamber #3..... 71

Fig. #29...H_2S Removal by Ozone..... 73

Fig. #30...H_2S Removal with 0.05 Molar Ammoniated Copper Chelate..... 85

Fig. #31...H_2S Removal with 0.04 Molar Copper Sulfate Plus Ammonia Gas..... 87

LIST OF FIGURES (Continued)

Fig. #32...H_2S Removal with 0.04 Molar Copper Sulfate Plus Chlorine Gas..... 89

Fig. #33...H_2S Removal with 0.04 Molar Copper Sulfate plus Chlorine Gas and Ammonia Gas..... 92

Fig. #34...H_2S Removal with 0.04 Molar Copper Ammonium Complex plus Chlorine Gas and Ammonia Gas. No PVC Disc Rotation. 94

Fig. #35...H_2S Removal with 0.04 Molar Copper Ammonium Complex Plus Chlorine Gas and Ammonia Gas. With PVC Disc Rotation..... 95

Fig. #36...H_2S Removal with Ammonia Gas. Tap Water In Contactor..... 102

Fig. #37...H_2S Removal with Chlorine Gas. Static Conditions..... 104

Fig. #38...H_2S Removal with Chlorine Gas. Dynamic Conditions..... 106

Fig. #39...H_2S Removal with Chlorine Gas at Constant 2.0 CFH Feed..... 108

LIST OF TABLES

Page

Table # 1...PVC and Cements: Bonding Comparisons..... 14

Table # 2..."Vari-Drive" Dial Settings, Equivalent R.P.M. and Contact Area.... 29

Table # 3...Total Oxygen Transfer Rate in Two Phase Contactor..... 32

Table # 4...Typical Analyses of Alvarado Filtration Plant Tap Water Effluent, May, 1968..... 40

Table # 5...Typical analyses of Alvarado Filtration Plant tap water effluent, June, 1968..... 41

Table # 6...Typical Analyses: Colorado River Water. Aqueduct #1..... 42

Table # 7...Typical Analyses: Colorado River Water. Aqueduct #2..... 43

Table # 8...H_2S Removal with Tap Water..... 44

Table # 9...H_2S Removal with pH Adjusted Tap Water..... 46

Table #10...H_2S Removal with 0.1 and 0.25% Caustic Soda..... 51

Table #11...H_2S Removal with 100 ppm, 200 ppm and 400 ppm available chlorine (From calcium hypochlorite)..... 54

Table #12...H_2S removal with 10,000 ppm, 15,000 ppm, and 20,000 ppm available chlorine (from calcium hypochlorite).. 56

Table #13...H_2S removal with 1.0%, 2.0%, 5.0% and 10.0% potassium permanganate..... 59

Table #14...Typical raw sewage analyses - Point Loma Plant..... 63

List of Tables (continued)

Table 15...H_2S removal with activated sludge..... 65

Table 16...H_2S removal with ozone..... 74

Table 17...H_2S removal with citric acid, ammonium citrate and citric acid - copper sulfate mixture..... 78

Table 18...H_2S removal with acetic acid..... 79

Table 19...H_2S removal with 1% cobalt sulfate.... 80

Table 20...H_2S removal with ammonium hydroxide and ammonium acetate..... 82

Table 21...H_2S removal with 0.05 molar copper chelate..... 84

Table 22...H_2S removal with 0.01 molar copper sulfate plus ammonia gas..... 86

Table 23...H_2S removal with 0.01 molar copper sulfate plus chlorine gas..... 88

Table 24...H_2S removal with 0.01 molar copper sulfate plus chlorine gas and ammonia gas..... 91

Table 25...H_2S removal with 0.01 molar copper ammonium complex plus chlorine gas and ammonia gas..... 93

Table 26...H_2S removal with morpholine..... 98

Table 27...H_2S removal with M-Pyrol..... 99

Table 28...H_2S removal with ammonia gas. Tap water in Contactor..... 101

Table 29...H_2S removal with chlorine gas. Static conditions..... 103

Table 30...H_2S removal with chlorine gas. Dynamic conditions..... 105

Table 31...H_2S removal with chlorine gas at constant 2.0 C.F.M. feed rate..... 107

FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

An investigation into chemical methods for treatment of foul air was conducted under a Federal Odor Control Grant in cooperation with the City of San Diego. A pilot liquid-gas contactor was constructed of PVC lining and stainless steel shafting. Several oxidizing and absorptive chemicals (tap water, sodium hydroxide, calcium hypochlorite, potassium permanganate, copper sulfate, copper chelate, etc.) as well as biologically active materials, were used in the contactor to remove the foul odors in air vented from the sewage sedimentation tanks. Under the experimental sulfide levels of 1.0 to 20.0 ppm H_2S (by weight in the gas) good removal was shown by commercial sodium hydroxide, gaseous chlorine and ammoniated copper chelate. Ozone, when used in conjunction with other reactive chemicals, helped in removal of odors other than H_2S, as well as H_2S. Sodium hydroxide (caustic soda) foamed excessively and would require continuous monitoring and automated feed control. Approximate costs (chemicals only) for treating 1,000,000 cubic feet* of foul air range from $0.18 to $46.00 depending on sulfide concentration and chemical used.

This report was submitted in fulfillment of Grant Number WPD 135-01-67 under the (partial) sponsorship of the Federal Water Pollution Control Administration.

*(28,318.5 cubic meters)

SECTION 1 - INTRODUCTION

The design and the prior use of a laboratory model two-phase liquid-gas contactor suggested the use of a larger pilot-size contactor to remove sulfides and other foul odors from vented air in sewage systems. (1) Thus, the use of a pilot liquid-gas contactor could determine the potential of foul-air treatment where other methods (incineration; masking by chemical agents) are unavailable, costly, or ineffective.

It was felt that a pilot plant handling 1,000-3,000 cubic feet of air per minute would serve to investigate the feasibility of liquid-gas extraction as a method of controlling sewage odors. (2) (3)

PROJECT OBJECTIVES

It was the general objective of this demonstration project to investigate the feasibility of liquid-gas extraction as a method of controlling sewage odors. Within this general goal, the following specific objectives were indicated:

a) To determine the reactant or reactants required for satisfactory deodorization of vented sewage gases. To investigate whether an oxidizer, reducer, absorber, chelator, or biological slime are necessary, singly or in combination.

b) To determine optimum temperatures and air retention times in the contactor for odor removal.

c) To determine whether the removal of H_2S alone would unmask trace amounts of other materials which could be equally offensive.

d) To estimate the economic parameters associated with liquid-gas extraction methods of sewage odor control in order to ascertain their feasibility in relation to other methods, particularly incineration.

DESCRIPTION

The two-phase contactor consists of a 4 ft. diameter x 6 ft. cylindrical drum mounted horizontally on a steel and wood platform. Inside the drum, a series of ventilated plastic discs are mounted on a stainless steel shaft. A "Vari-drive" unit controls the rotational speed of the shaft and its discs, thus making possible a variable contact surface from 5,000 to 40,000 square feet per minute. See Figs. #1, #2, and #3. Ref. (4).

PLAN OF OPERATION

Reagents investigated were tap water, calcium hypochlorite (5), caustic soda (6), potassium permanganate (5), activated sludge, chelates, ozone (5), citrates, cobalt, morpholine, M-pyrol, copper sulfate, ammonia and chlorine gases (5), and copper ammonia complexes.

AVAILABLE FACILITIES

The Point Loma Metropolitan Waste Water Treatment plant is a fairly new (since 1963) primary treatment plant with separate sludge digestion and an effluent ocean outfall. It was designed for an ultimate capacity of 234 million gallons per day, averaging a flow of about 85 M.G.D. at present (June 1970). This plant treats the sewage generated by the City of San Diego and eleven nearby participating agencies (cities, sanitation districts, etc,).

The Water Utilities Department of the City of San Diego operates two main laboratories for the chemical and biological analyses of water and waste water, oils, lubricants, construction and highway materials, as well as many other products purchased by the city. The laboratories are well equipped, having facilities for gas chromatography, infra-red and visible-range spectroscopy, radioactivity counting equipment, fume hoods and a full assortment of analytical balances, ovens and other required conventional

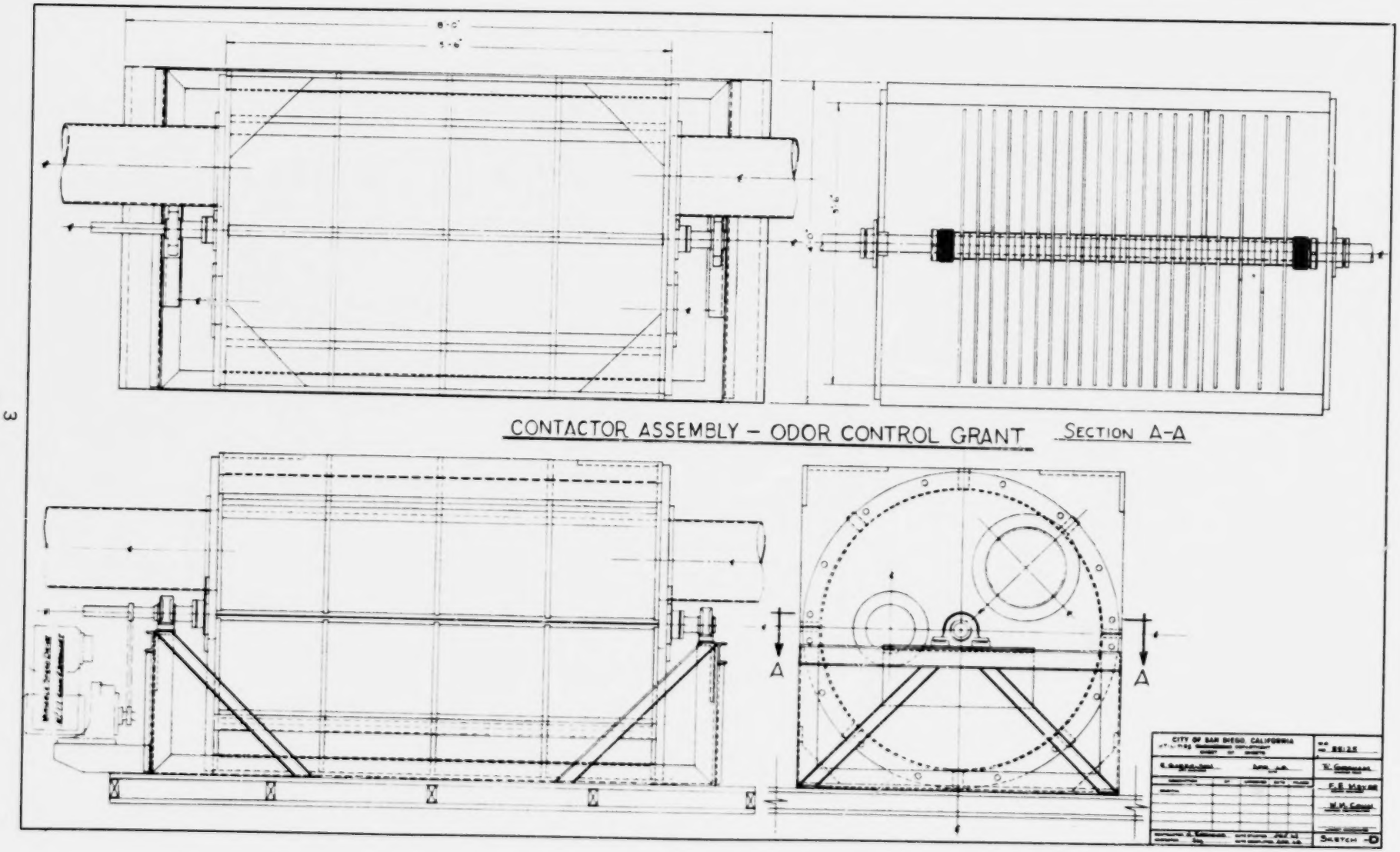
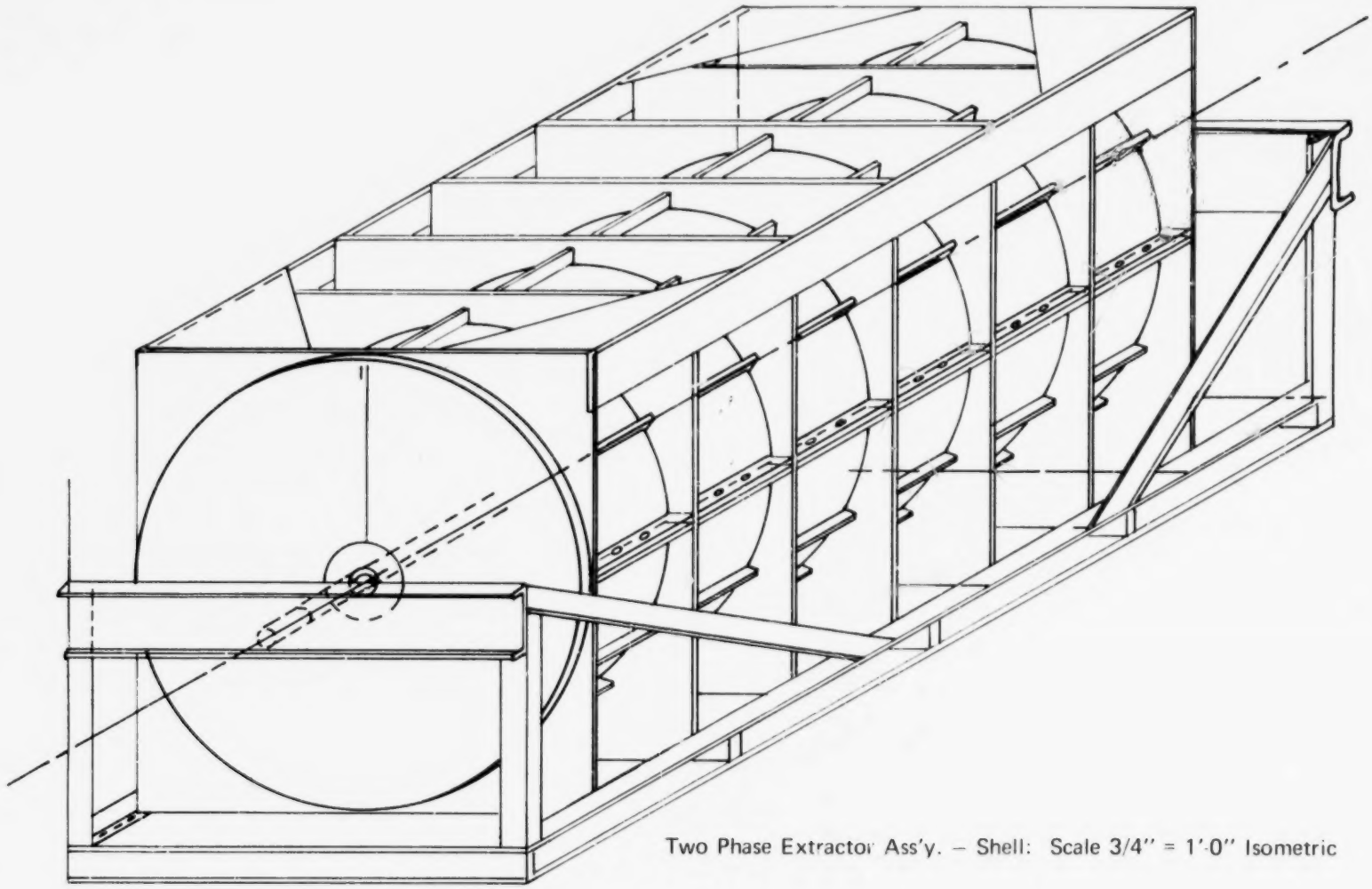

CONTACTOR ASSEMBLY – ODOR CONTROL GRANT
SECTION A-A
A
A
CITY OF SAN DIEGO, CALIFORNIA
SKETCH -D

FIG. #1



Two Phase Extractor Ass'y. – Shell: Scale 3/4" = 1'-0" Isometric

FIG. 2

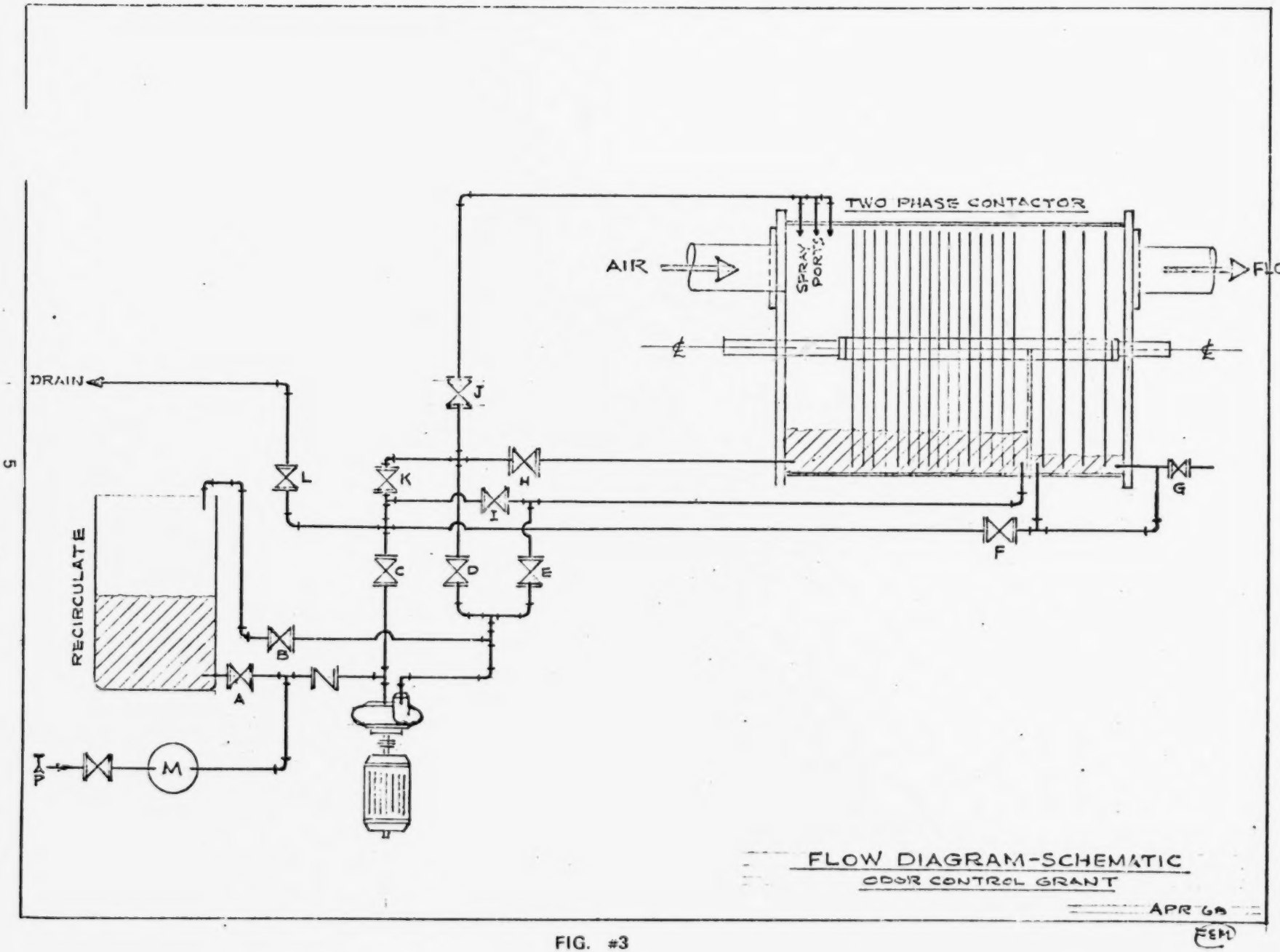

TWO PHASE CONTACTOR
AIR
SPRAY PORTS
FLOW
DRAIN
RECIRCULATE
J
K
L
H
I
G
F
C
D
E
B
A
M
TP
FLOW DIAGRAM-SCHEMATIC
ODOR CONTROL GRANT
APR 69
FEH

FIG. #3

laboratory equipment. One of the laboratories is located at the Point Loma Treatment Plant, where the demonstration liquid-gas two-phase contactor is located. The construction design at Point Loma is such that the foul air is fully contained and collected into one central disposal system. The actual study was made from a metered vent from the main duct system. See Fig. #14.

REFERENCES: see 1, 2, 3, 4, 5, 6 in Bibliography

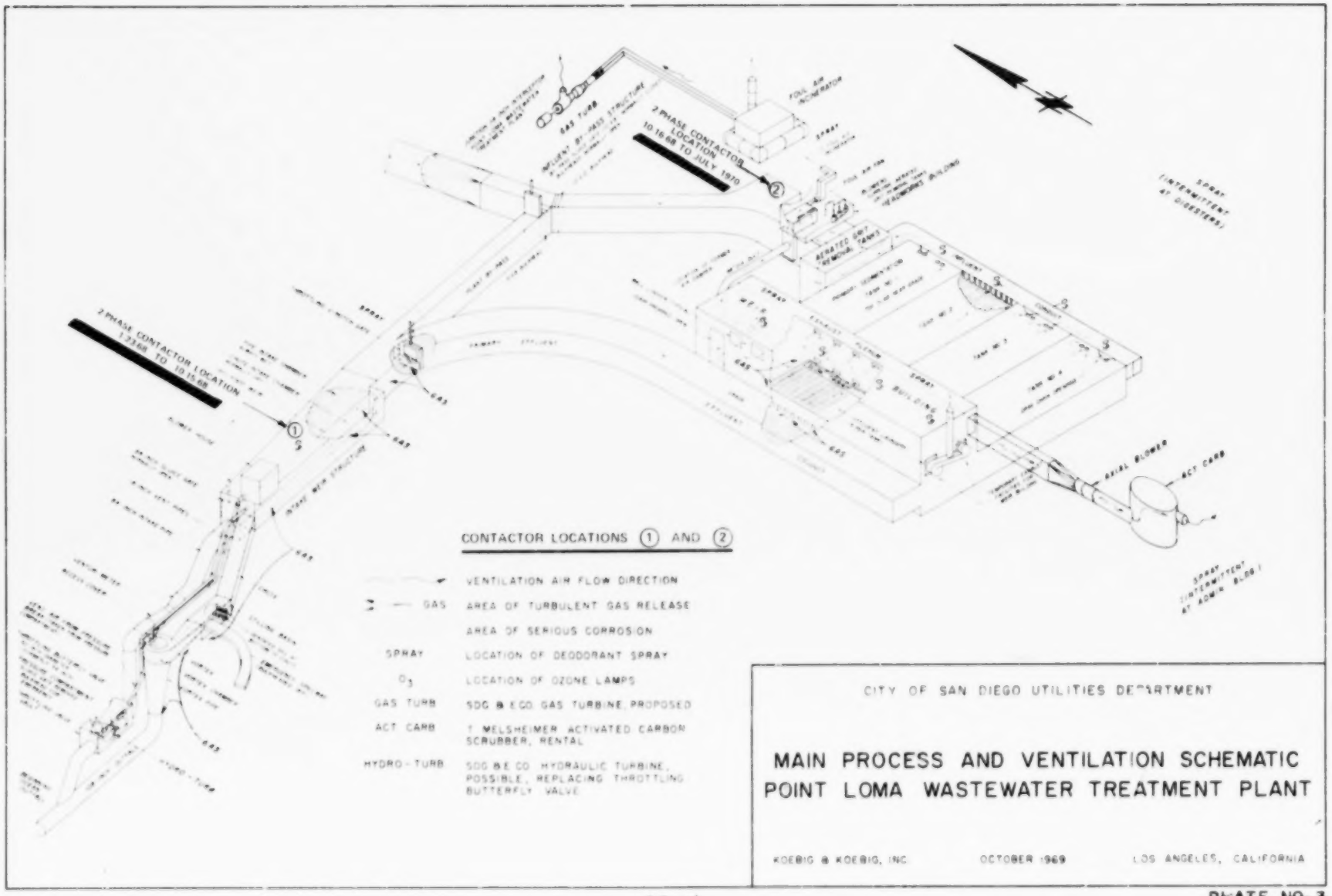

2 PHASE CONTACTOR LOCATION 10.16.68 TO JULY 1970
2 PHASE CONTACTOR LOCATION 1.1368 TO 10.15.68
GAS TURB
INFLUENT PT. LOMA STRUCTURE
FOUL AIR INCINERATOR
AERATED GRIT REMOVAL TANKS
PRIMARY SEDIMENTATION
AXIAL BLOWER
ACT CARB
SPRAY (INTERMITTENT AT DIGESTERS)
SPRAY (INTERMITTENT AT ADMIN BLDG.)
CONTACTOR LOCATIONS (1) AND (2)
VENTILATION AIR FLOW DIRECTION
GAS — AREA OF TURBULENT GAS RELEASE
AREA OF SERIOUS CORROSION
SPRAY — LOCATION OF DEODORANT SPRAY
O_3 — LOCATION OF OZONE LAMPS
GAS TURB — SDG & E CO. GAS TURBINE, PROPOSED
ACT CARB — T. MELSHEIMER ACTIVATED CARBON SCRUBBER, RENTAL
HYDRO-TURB — SDG & E CO. HYDRAULIC TURBINE, POSSIBLE, REPLACING THROTTLING BUTTERFLY VALVE
CITY OF SAN DIEGO UTILITIES DEPARTMENT
MAIN PROCESS AND VENTILATION SCHEMATIC
POINT LOMA WASTEWATER TREATMENT PLANT
KOEBIG & KOEBIG, INC. OCTOBER 1969 LOS ANGELES, CALIFORNIA

FIG. #4

PLATE NO. 3

SECTION 2 - SUMMARY AND CONCLUSIONS

1. Studies under the odor control investigation have shown that chemical removal or oxidation of sulfide odors is possible using a liquid-gas two-phase contactor. Since atmospheric levels of H_2S above and higher than 0.5 - 1.0 ppm by weight are obnoxious and difficult to mask either by air dilution or masking agents, this level (0.5 - 1.0 ppm H_2S) was considered a maximum for satisfactory discharge of treated foul air from the contactor.

2. The capabilities of many reactants for removal of H_2S were investigated through the use of the contactor and its ducts. Among the reactants studied were: Tap water (ambient or adjusted to pH 9-10), caustic soda, calcium hypochlorite, potassium permanganate, activated sludge, ozone, citric acid, ammonium citrate, acetic acid, ammonium acetate, cobalt sulfate, copper sulfate, copper chelate, morpholine, M-Pyrol, ammonia gas, and chlorine gas.

3. This study revealed that certain chemicals are more efficient than others in the removal of H_2S present in foul air, leaving 0.0 to 1.0 ppm H_2S in the discharged air. The reactants that showed the best hydrogen-sulfide removal were: chlorine gas, caustic soda and copper ammonia chelate solutions in that order. In certain cases, it was noted that the use of ozone also eliminated the foul odor that was not due to H_2S. Ozone application could not be quantified to determine the ozone strength.

4. There were certain operational difficulties with some of the reactants so investigated. Potassium permanganate and morpholine leaked out through plumbing fixtures, while high concentrations of caustic soda caused excessive foam. Owing to its high vapor pressure, morpholine was lost to the atmosphere rather fast. Caustic soda was found to be efficient and inexpensive, although its entrainment would require secondary scrubbing to eliminate foam discharge to the atmosphere.

   Chlorine gas reacts readily with hydrogen sulfide, but it should be fed with automatic controls. Moreover, the gases discharged to the atmosphere

should be monitored to reduce hazards to personnel and equipment. Washing of chlorine-treated discharged air is necessary.

5. From close observations during experimental runs, total removal of hydrogen sulfide seems to be proportional, among other factors, to its partial pressure in input foul air, since H_2S removal drops sharply when H_2S concentration in input foul air decreases. This drop takes place even though other experimental conditions are kept constant.

6. The experimental two-phase contactor as built seems to be adequate to treat about 1,000 C.F.M. of foul air; for larger air volumes, a larger contactor is necessary.

7. A projection of cost of chemicals for treatment of 1,000,000 cubic feet (28,318.5 cubic meters) of foul air is included, based on the following considerations:

Treatment cost of 1,000,000 Cubic Feet (28,318.5 Cubic Meters) Foul Air (See Note):

Input Range of H_2S in ppm by weight	Chemical needed to treat 1,000,000 cu. ft. of foul air	Chemical Cost in $ per lb.	Cost to treat 1,000,000 cu. ft. foul air
1.8 - 2.4	1.8 lb. Sodium Hydroxide (Calculated using 50% commercial Caustic Soda)	$0.10	$0.18
11.0 - 14.0	10.8 lb. Chlorine Gas	$0.03 $0.10	$0.32 $1.08
8.0	2.9 lb. Ammonia Gas	$0.175	$0.51
0.2 - 0.8	1.6 lb. Calcium Hypochlorite	$0.86	$1.38
3.0 - 11.0	13.4 lb. Potassium Permanganate	$0.48	$6.45
32.0	16.9 lb. 58% Ammonium Hydroxide (2.35 gal.)	$0.83	$14.00
1.5 - 3.6	42.5 lb. Calcium Hypochlorite	$0.86	$37.00
7.0 - 8.8	53.0 lb. Calcium Hypochlorite	$0.86	$46.00

Incineration Overall Cost (see note):

Point Loma Plant	(Sludge Gas Fired)	-	$2.96 per 1,000,000 cu. ft.
	(Butane Fired)	-	$5.31 "
Pump Station #1	(Butane Fired)	-	$4.03 "
Pump Station #2	(Butane Fired)	-	$4.43 "

NOTE: The chemical removal of hydrogen sulfide is based on chemical cost only, whereas incineration cost includes operation, maintenance and fuel, if purchased.

SECTION 3 - RECOMMENDATIONS

Based on foregoing conclusions, the following recommendations are made:

1. Based on these investigations, a rotating-disc two-phase contactor is not recommended for large foul air scrubbing installations primarily because of cost factors.

2. In lieu of the rotating-disc contactor used in these studies, it appears that a packed tower with counter-current flow of liquid chemical against an updraft of foul air is more feasible.

3. A gaseous agent such as chlorine, with or without caustic or alkaline-buffered solutions, is recommended for scrubbing in a packed tower. This agent should be used in a tower designed for minimum power demand. The tower should eliminate any escape of gaseous chlorine compounds.

4. For rotating-disc contactors with high foul-air flows (over 1,000 C.F.M.), caustic soda, chlorine gas, or copper ammonia chelate is recommended; however, scrubbing equipment is required to treat the exhaust air.

5. For low foul-air flows (5-250 C.F.M.), potassium permanganate or copper ammonia chelate is recommended. The use of these chemicals would not require secondary scrubbing equipment.

6. For intermediate air flows (50-1,000 C.F.M.), copper ammonia chelate is recommended. This agent is relatively simple to handle and has a low material cost factor.

7. Safety precautions are recommended when working with caustic soda or chlorine gas.

8. Continued investigations into the direct generation of chlorine compounds by electrolysis from sea water and brine for foul-air scrubbing is recommended. The City of San Diego is currently conducting limited studies to investigate the feasibility of such chlorine generation.

9. Recent work with biological solutions (e.g. nitrifying activated sludge) warrant continued studies.

SECTION 4 - DESIGN STAGE

OF THE TWO PHASE CONTACTOR

A request was made to a manufacturer for a suitable two phase contactor (in size and construction) with the capacity of 3,000 C.F.M. of foul air.

The manufacturer informed the City of San Diego that a two phase contactor was not available for outright sale, but would lease such a unit to the city. After a correspondence exchange with said manufacturer, the advisory staff felt that the increased lease price and restrictions were excessive, and as a result negotiations for the City of San Diego to lease a pre-fabricated two phase contactor were abandoned in March 1967.

Fred Meyer, design engineer, investigated the cost of a similar unit made of stainless steel. Several bids were sent out, and only one bid was received. The bid price for such a unit was in excess of available funds. Since the grant fund allowance for the unit was $5,500.00, it was decided to ask permission of the Federal Water Quality Control Administration to construct a two phase contactor unit. Permission to build such a unit was received from the U.S. Department of the Interior, Federal Water Quality Control Administration. In April 1967, Fred Meyer and staff of the City of San Diego, Utilities Engineering Section, designed the plans for construction of the two phase contactor. The unit was built with a marine plywood shell with reinforcing PVC linings and PVC discs attached to a stainless steel shaft.

SECTION 5 - CONSTRUCTION AND EXPERIMENTAL FABRICATION

The outer shell of the two phase contactor was constructed by the City of San Diego carpentry shop according to specifications furnished by Fred Meyer and made of a marine plywood framework for outer shell with hardwood reinforcement, and provided with a steel reinforced base built by the maintenance shop using a heavy design (2" X 8" channel iron) to prevent mid-deflection of contactor. Since the inner shell construction was to be PVC, a series of tests were run on bonding agents.

TESTING OF ADHESIVES FOR PVC (POLYVINYL CHLORIDE) FABRICATION

PURPOSE: To determine: a) Suitability of adhesives to cement PVC to plywood and PVC to PVC, and b) Resistance of bonds to chemicals and reagents to be tested.

METHODS: Various adhesives were used according to instructions on plywood to PVC and PVC to PVC bonds. Fred Meyer was informed by a plastic distributor representative that some types of PVC sheeting had been rolled out with a silicone lube or release agent, who suggested that the contacting face part of plastic sheets be sanded before applying adhesive.

Adhesives tried were: 1) Epoxy scotch-weld, 2) I.P.S. cement, 3) Formica contact cement, and 4) Fiber glass resin from the carpenter shop. The adhesives were tested on: a) Plywood to sanded PVC, b) Sanded PVC to sanded PVC, c) Plywood to smooth PVC, d) Smooth PVC to smooth PVC. See Table #1.

A series of small panels coated with fiberglass resin were checked for chemical resistance. The resin failed to stop caustic soda and potassium permanganate in 24-hour penetration test.

TAPLE #1

CHARACTERISTICS OF SEVERAL BONDS

	EPOXY SCOTCH WELD		I.P.S. CEMENT		FORMICA CONTACT CEMENT		FIBERGLASS RESIN
	Strength	Elasticity	Strength	Elasticity	Strength	Elasticity	
Plywood to sanded PVC	Excell.	Excell.	Fair	Fair	Very good	Very good	
Sanded PVC to sanded PVC	Very good	Very good	Excell.	Very good	Good	Good	
Plywood to smooth PVC	Very good	Very good	Poor	Poor	Good	Good	
Smooth PVC to smooth PVC	Good	Good	Good	Poor	Good	Good	
Appearance	Excell. Glossy finish		Fair, slight rough (tacky, spreads uneven)		Irregular (hard to remove evenly)		
1% NaOH	No effect		No effect		No effect		Failed in 24-hr. test (leakage)
5% $KMnO_4$	No effect		No effect		No effect		Failed in 24-hr. test (leakage)

TEST RESULTS

On the basis of these tests, Epoxy Scotch-weld adhesive was chosen to bond sanded PVC to the plywood shell. I.P.S. cement was chosen to bond sanded PVC to sanded PVC in inner layers of contactor.

The construction seal chosen for the two phase contactor and PVC ducting was silicone rubber, due to its resistance to chemicals, and ease with which bonds so made could be broken and re-made after maintenance or alterations to unit.

PVC Plastic (polyvinyl chloride) type 1-plasticized was used throughout for construction. Double layering of 1/16" PVC strips on inner surfaces of plywood shell (See Fig. #5) was accomplished by using thin strips for fit and sandbagging for pressure contact.

Originally, a 36-disc unit was planned, but later the size was cut back to a unit with a total of 20 discs (16 discs in extraction section and 4 discs in demister section) due to spacing details and increasing costs of construction.

The 12" I.D. (with 0.005" tolerance) PVC ducts and 1/4" flanges were constructed of a similar 1/16" PVC sheeting molded over forms and cemented together with Scotchweld Epoxy. These ducts were used for input foul air to the two phase contactor and treated-air discharge with flanges sealed together with silicone rubber.

DRILLING OF 41" PVC DISCS

To accomplish 20% voids, a series of 1" holes were drilled in each disc (335 holes per disc), and each hole counter-sunk to streamline flow and stop liquid pumping. (See Fig. #6).

Shaft mounting hubs for the discs were turned out by lathe from 6" round stock and pinned together with stainless steel pins, and secured lengthwise with PVC locking nuts.

Reproduced from
best available copy.

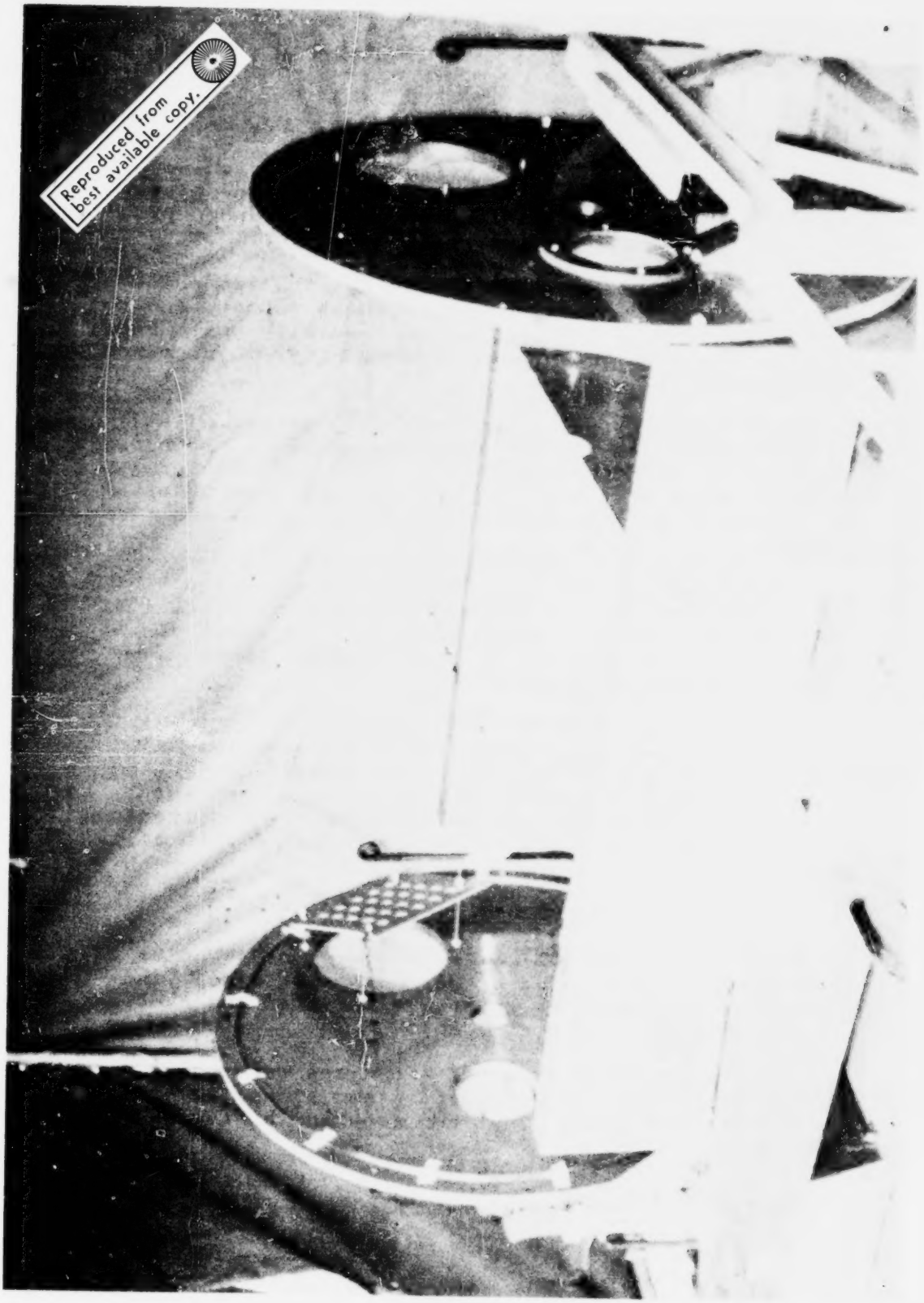


FIG. =5
SIDES AND BOTTOM OF TWO PHASE CONTACTOR

The unit to power the stainless steel shaft with PVC discs was a (Sterling) variable speed drive or "Vari-drive", including motor, drive and base. This vari-drive was connected to the shaft by a dual belt drive, and later, changed to a #40 link chain to avoid slippage under heavy torque. (See Fig. #7).

SPECIFICATIONS OF THE TWO PHASE CONTACTOR AS CONSTRUCTED

The unit has a channel iron base and plywood outer shell reinforced by outside framework of hardwood - inner lining is two layers of 1/16" PVC.

OVERALL DIMENSIONS (Extraction plus demister sections)	41 3/4" I.D. x 66" long
GROSS VOLUME	52.218 cubic feet
NET VOLUME (less shaft, discs, spacers, hubs, bulkhead)	48.57 cubic feet
WORKING VOLUME (when 15 gal. of liquid in contactor)	46.60 cubic feet
DEMISTER SECTION	41 3/4" x 17 $\frac{1}{2}$" long
BULKHEAD	18" section $\frac{1}{4}$" thick. Located between extraction and demister sections.
STAINLESS STEEL SHAFT	$2\frac{1}{4}$" dia. x 66" long.
EXTRACTOR SECTION	16 perforated PVC discs 41" O.D. x $\frac{1}{4}$" thick.
DEMISTER SECTION	4 perforated PVC discs 41" O.D. x $\frac{1}{4}$" thick.
20% VOID PER DISC	335 holes 1" dia.; counter-sunk
AREA PER DISC	7.22 square ft. one side, 14.44 square ft. two sides.
AREA, 16 DISCS	231.06 square feet
AREA, 20 DISCS	288.82 square feet

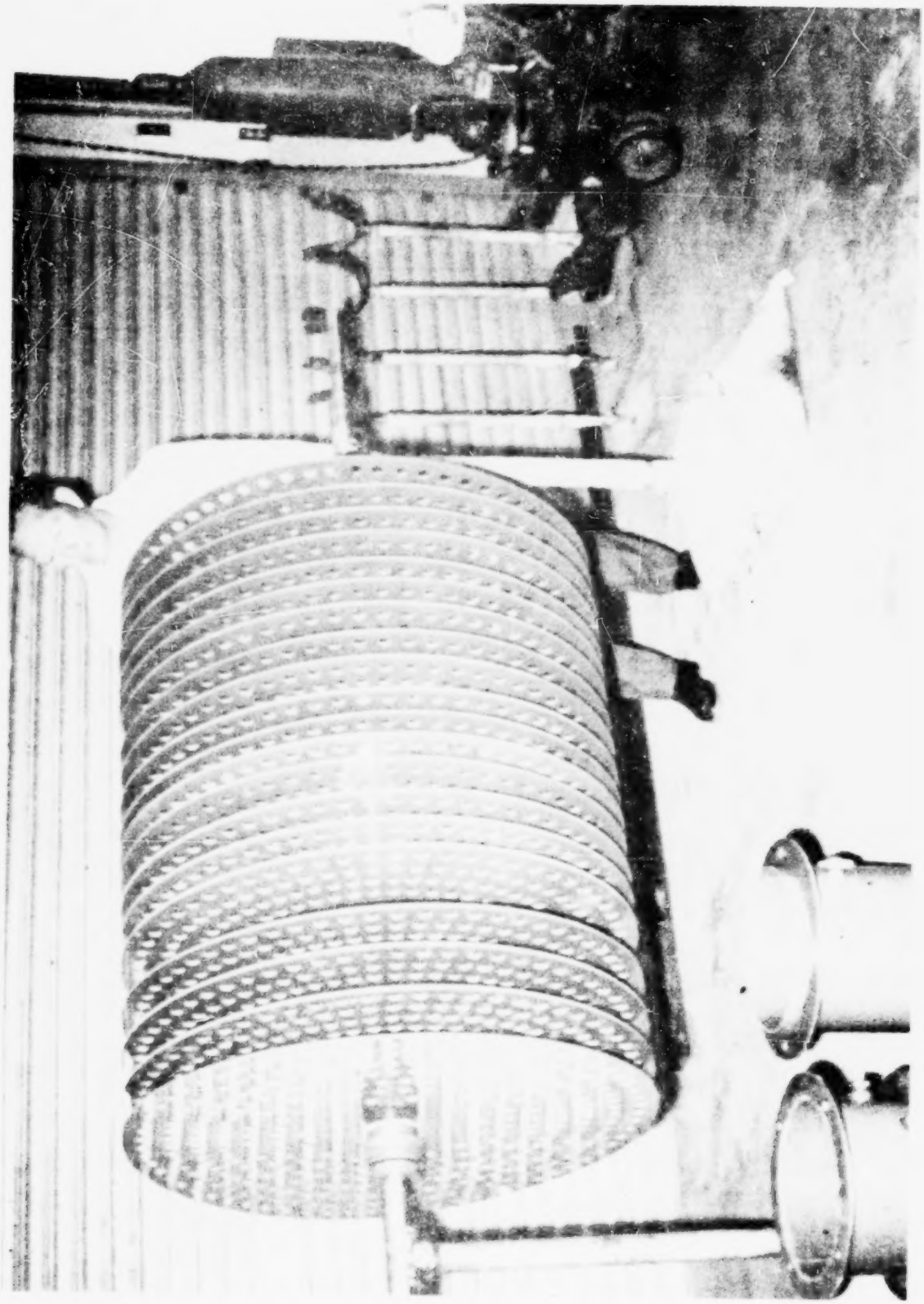


FIG. =6
PERFORATED PVC DISCS AND STAINLESS STEEL
SHAFT OF TWO PHASE CONTACTOR

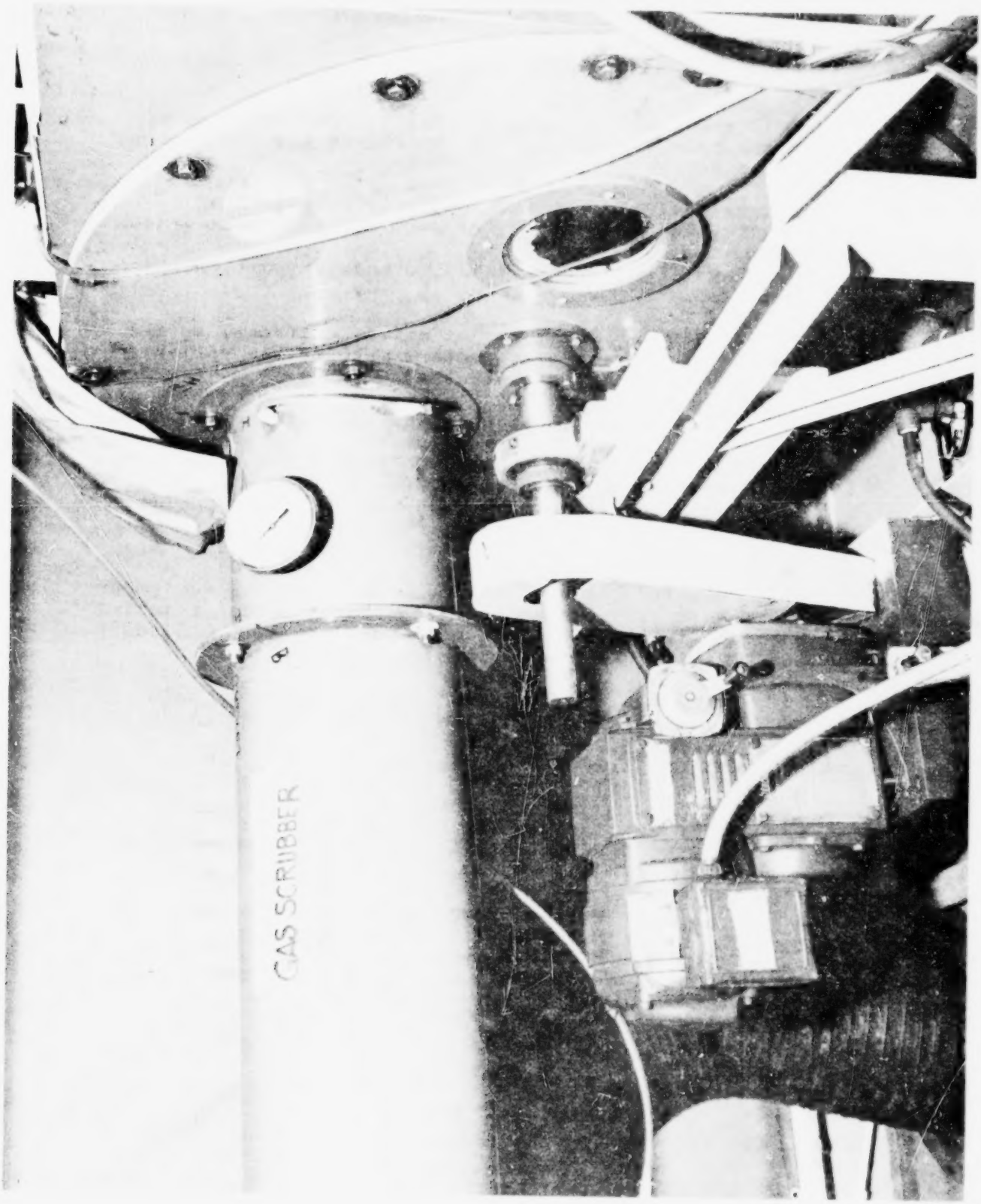


FIG -7
"VARI DRIVE" ASSEMBLY OF TWO PHASE CONTACTOR

Fabrication of the PVC ducts proved difficult during cold weather (below 50° F.) as the PVC sheets tended to shatter like glass.

Overall size of the contactor limited its capacity to 1,000 C.F.M. of foul air for treatment.

Leveling jacks attached to base of unit, wiring installed.

Various arrangements of drive, orifices, sprays, pumps, and orifice plate meters make this a variable two phase liquid-gas contactor.

The completed contactor was sealed up on January 10, 1968, and moved out to the effluent channel on January 23, 1968. Later, to obtain a more uniform concentration of hydrogen sulfide in foul air, the contactor was relocated outside of headworks building, north side, using a portion of the foul air ducted from sedimentation tanks to the incinerator.

Therefore, and in review, the following equipment was needed to implement the two phase contactor in addition to basic PVC lined plywood shell, PVC discs and 12" I.D. PVC ducts:

Mechanical "Vari-drive" for operation of main shaft holding PVC discs so that a range of 10 - 200 R.P.M. is available.

"Vari-drive" Specifications:

(Sterling) $\frac{1}{2}$ H.P. drip proof motor - integral construction 115 volts single phase.

Torque: Approximately 100 inch-lbs output at 220 R.P.M. and 700 inch-lbs. at 22 R.P.M.

Output Speed: Approximately 22 - 220 R.P.M., with a limiting factor of 80 R.P.M. when 20 gal. are inside contactor, or, if allowing for a good safety margin, maximum working speed to be 65 R.P.M.

Pump for recirculation of water or chemicals and to supply the sprays within the two phase contactor itself.

Pump Specifications:

(Deming Pianite) centrifugal pump, 1½" suction - 1" discharge. Approximately 40 G.P.M. at 60 ft. head. 1 H.P., 3-phase motor, 3500 R.P.M. plastic case and impeller with stainless steel shaft and plastic seal o (Crane type 21).

To complete connections between contactor, holding tank and recirculation pump, 2" standard PVC pipe (schedule #40-threaded) and clear, flexible PVC tubing was used, along with several ball and globe PVC valves to control the flow of reacting chemicals. Other miscellaneous fittings were of schedule #40 PVC (Heavy duty), threaded - with teflon tape used as thread sealant.

Control panel for pump motor and "Vari-drive" motor, and instrumentation outlets. Sprays and manifolding.

Gas meters and flow meters - gas orifices for regulating flow and manometer to monitor resistance to flow across unit.

Wet and dry bulb thermometers (Psychrometer) for monitoring of percent relative humidity in input and discharged air. Dial thermometers for input and discharge temperatures of gas and liquid.

Source of 100 and 1,000 C.F.M. air and foul air. Operating controls - valves for pump, control of sprays, drains. Tachometer or Veeder counter for shaft R.P.M.

As protection for contactor and other equipment, a dacron weatherproof cover with steel framework to support it was obtained.

Miscellaneous fittings for plumbing.

Finished two phase contactor is shown in Fig. #8 and Fig. #9.

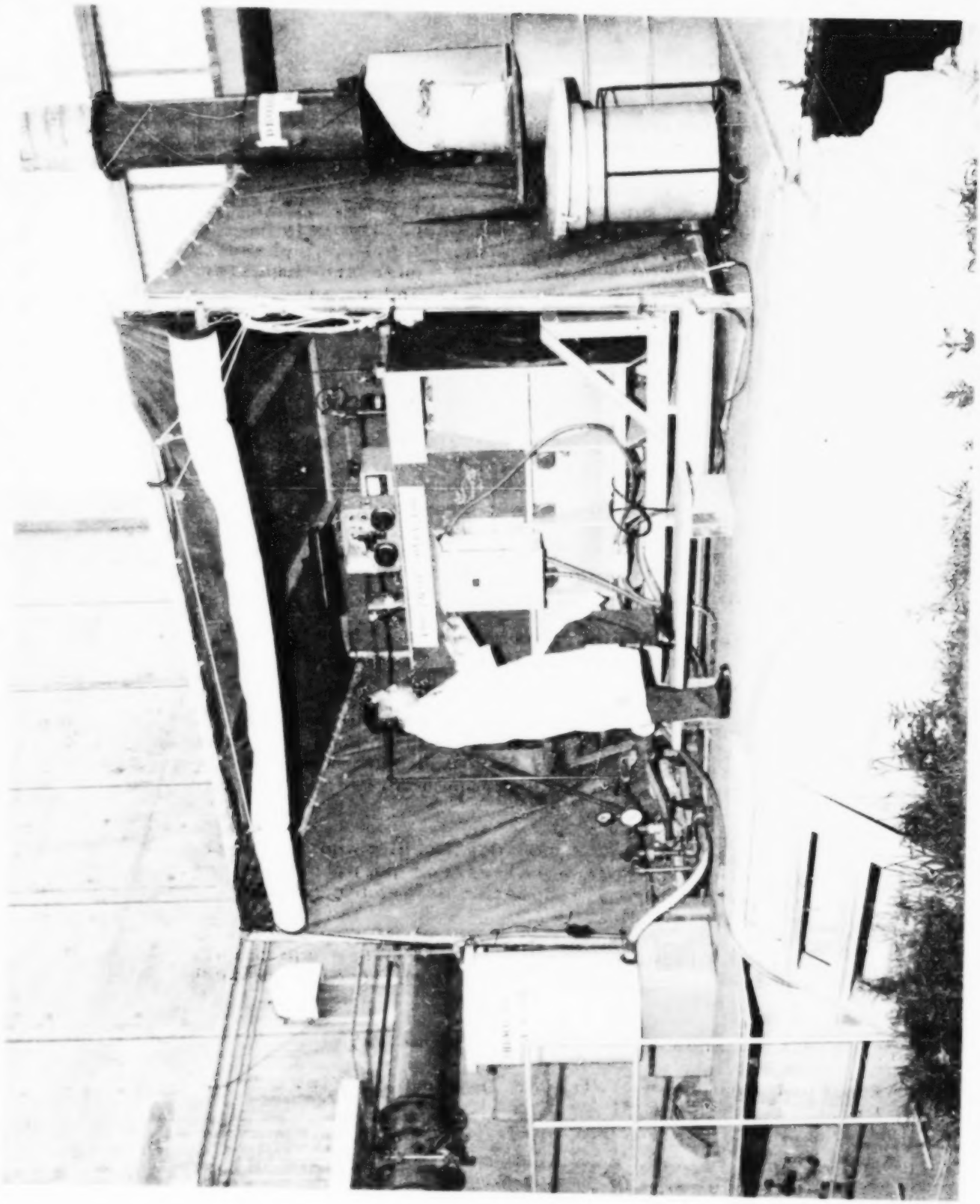


FIG. =8
VIEW OF PVC DUCTS, TANK AND TWO PHASE CONTACTOR

Reproduced from
best available copy.

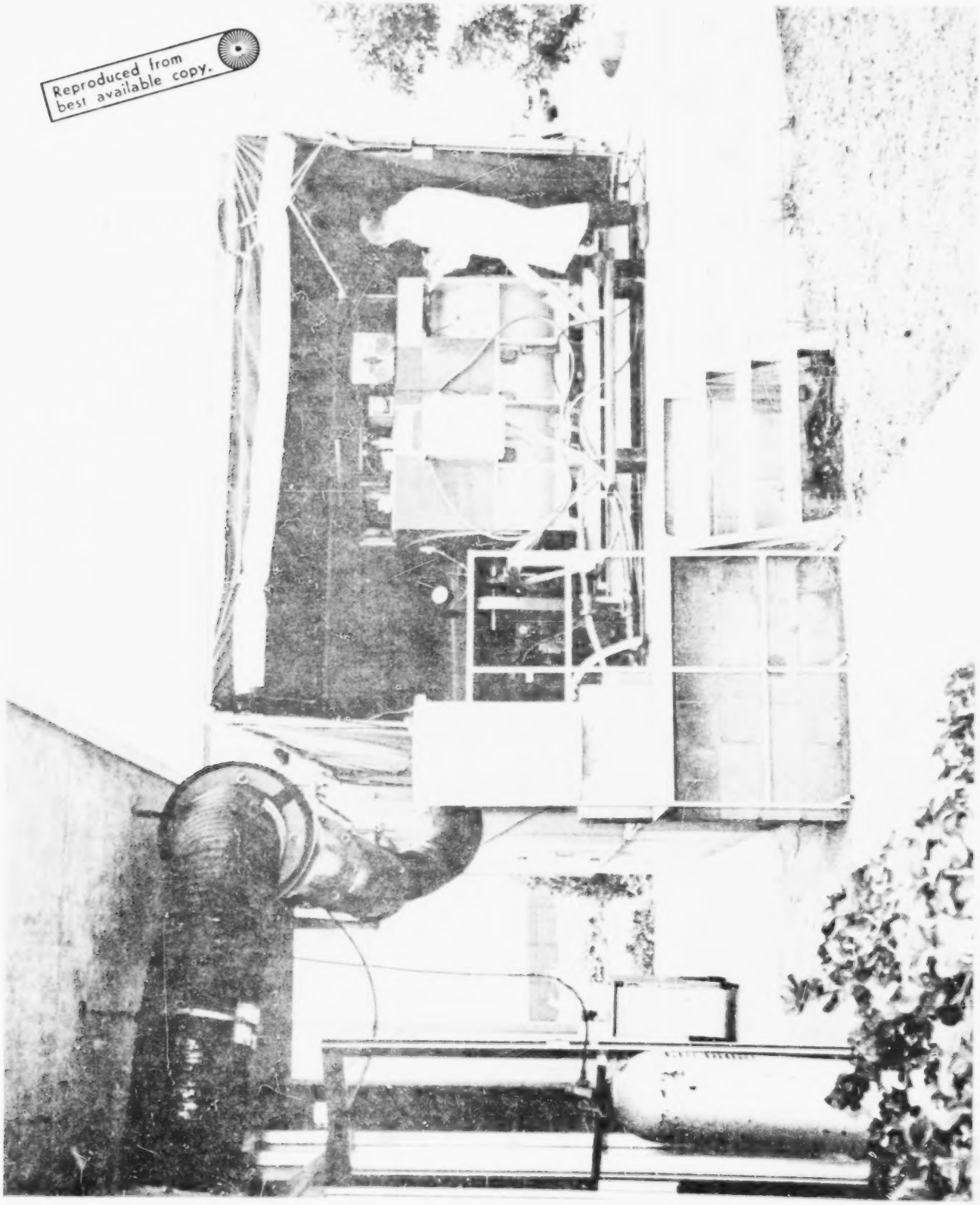


FIG. #9
VIEW OF PVC DUCTS, TANK AND TWO PHASE CONTACTOR

SECTION 6 - OPERATIONAL AND EVALUATION PHASE

DETERMINATION OF AIR FLOW

The main PVC duct was constructed as a measuring tube 12" I.D. (± 0.05" tolerance), using restricting Daniel orifices of 8" and 10" I.D. This measuring tube has 8 diameter (8 feet) duct lengths ahead of measuring spool (manometer mounted) and 4" diameter duct lengths after it. Transverse velometer readings were performed regularly to obtain linear feet flow per minute, and from them calculate the air volume going through the duct. The manometer mounted on the measuring spool (mm water) furnishes a constant daily check on volume of foul air to two phase contactor.

Fig. #10 shows relationships between mm H_2O pressure and velocity and volume of foul air. Fig. #11 shows residence time versus air flow. This confirms preliminary tests that indicate the overall size and resistance of air flow limit the capacity of the two phase contactor to 1,000 C.F.M. of air.

CALIBRATION OF LIQUID LEVELS IN HOLDING TANK AND CONTACTOR

The chemical holding tank was calibrated by liter additions plus mathematical conversion to gallons posted on the tank. The two phase contactor calibration was performed by making known additions of water, with continuous measurement of liquid level both at front and rear of extraction chamber, and demister section.

Volume through the recirculation pump to holding tank and sprays was determined by using a flow meter mounted on the pump discharge. A pressure gauge was used to check and maintain a constant flow to the sprays, and maintain flow recirculation to the two phase contactor.

TOTAL CONTACT AREA PER MINUTE

The "Vari-drive" dial setting was calibrated by an electronic tachometer to determine the R.P.M. of the driven shaft (disc mounting shaft). A #40 chain drive was used to transmit power. Fig. #12 shows

AIR DUCT FLOW

12" P.V.C. AIR DUCT TO TWO PHASE CONTACTOR

10 - POINT TRANSVERSE - "ALNOR" VELOMETER

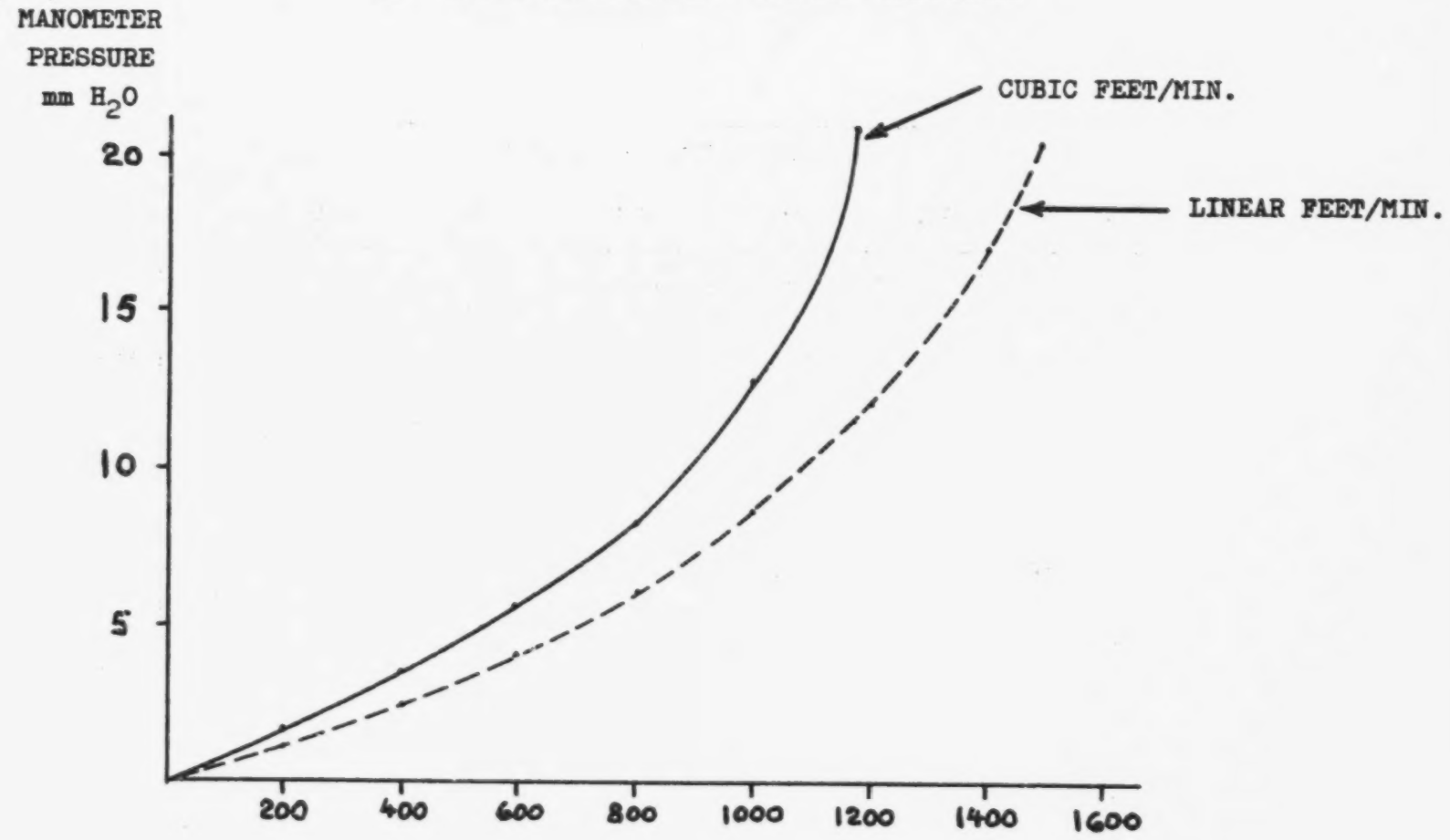


FIG. #10

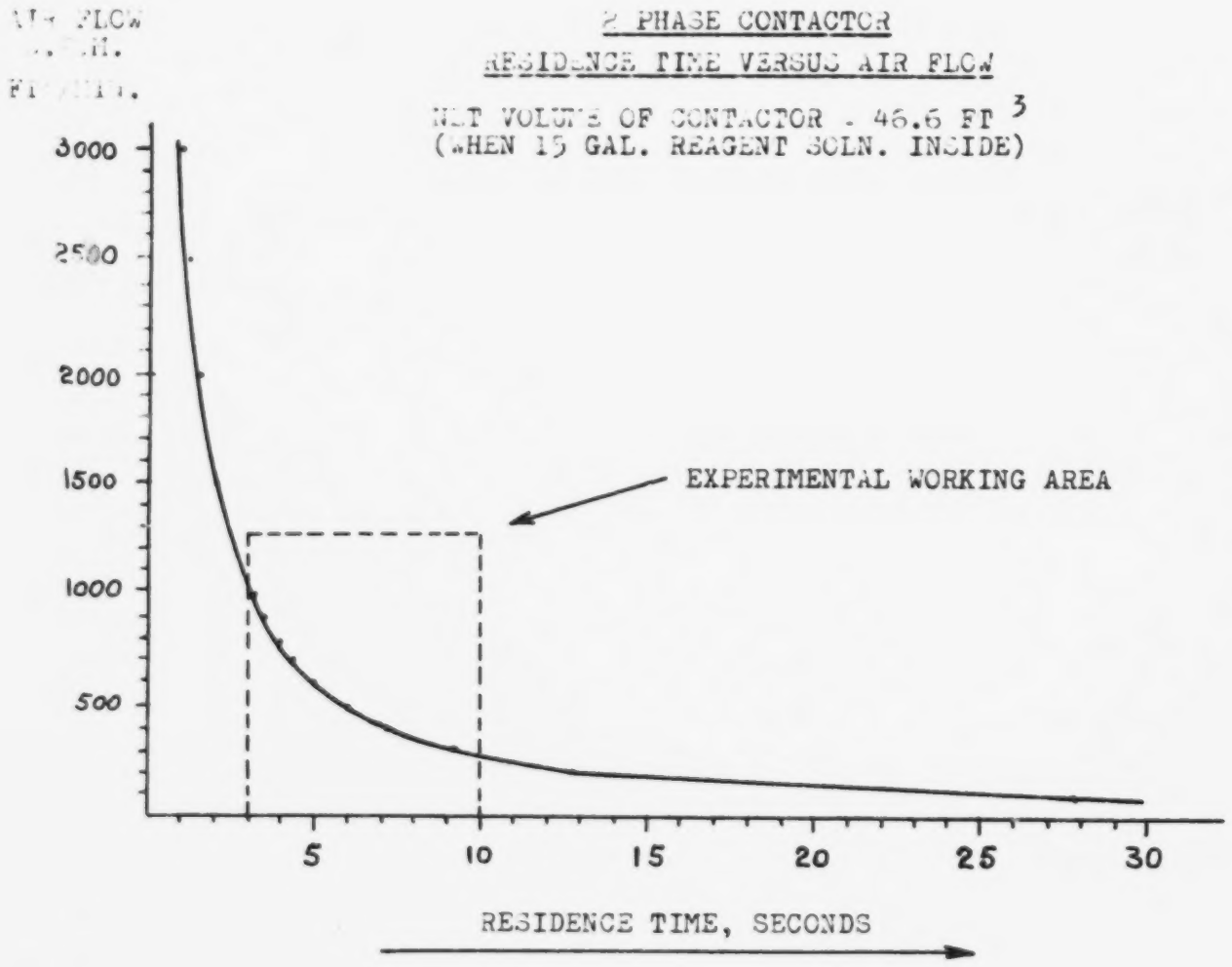

2 PHASE CONTACTOR
RESIDENCE TIME VERSUS AIR FLOW
NET VOLUME OF CONTACTOR - 46.6 FT 3
(WHEN 15 GAL. REAGENT SOLN. INSIDE)
3000
2500
2000
1500
1000
500
EXPERIMENTAL WORKING AREA
5
10
15
20
25
30
RESIDENCE TIME, SECONDS

FIG. #11

R.P.M. disc speed given by "Vari-drive" settings. Table #2 shows dial settings with equivalent R.P.M. of the discs, and equivalent contact area of extraction section, and total contact area (extraction and demister sections together).

WORKING VOLUMES

Without solution recirculation there were 15 gallons of reactant in the contactor. Under recirculation conditions, there were 15 gallons of solution in the contactor and 35 gallons in the holding tank.

The two phase contactor showed evaporating effect (cooling) and water saturation of foul air through unit (increase in the % of relative humidity). See Tables for some of % R.H. values.

Mechanical tests of the two phase contactor were started, and a disc speed of 223 R.P.M. reached - with very little vibration noted, when contactor was empty.

Operation when liquid was contained in contactor resulted in overloading of the variable drive motor as the speed increased or water level raised. 20 gal. liquid and 90 R.P.M. disc speed was found to be the absolute maximum for the ½ H.P. "Vari-drive" motor, while operating without air flow through unit. Increasing the water level without reducing the R.P.M. of disc shaft - or increasing R.P.M. above this figure (20 gal. at 90 R.P.M. disc) resulted in overloading and thermal cut-out of "Vari-drive" motor.

H.P. REQUIREMENTS AT GIVEN DISC R.P.M. AND 15 GAL. VOLUME IN CONTACTOR

H.P. requirements were determined by the use of an ampere-draw meter. It was found that speeds in excess of 90 R.P.M. with 20 gal. water in extraction chamber resulted in excessive current draw, 125% overload rating.

DISC R.P.M. SPEED

TWO PHASE CONTACTOR

#40 CHAIN DRIVE
15 GAL. WATER

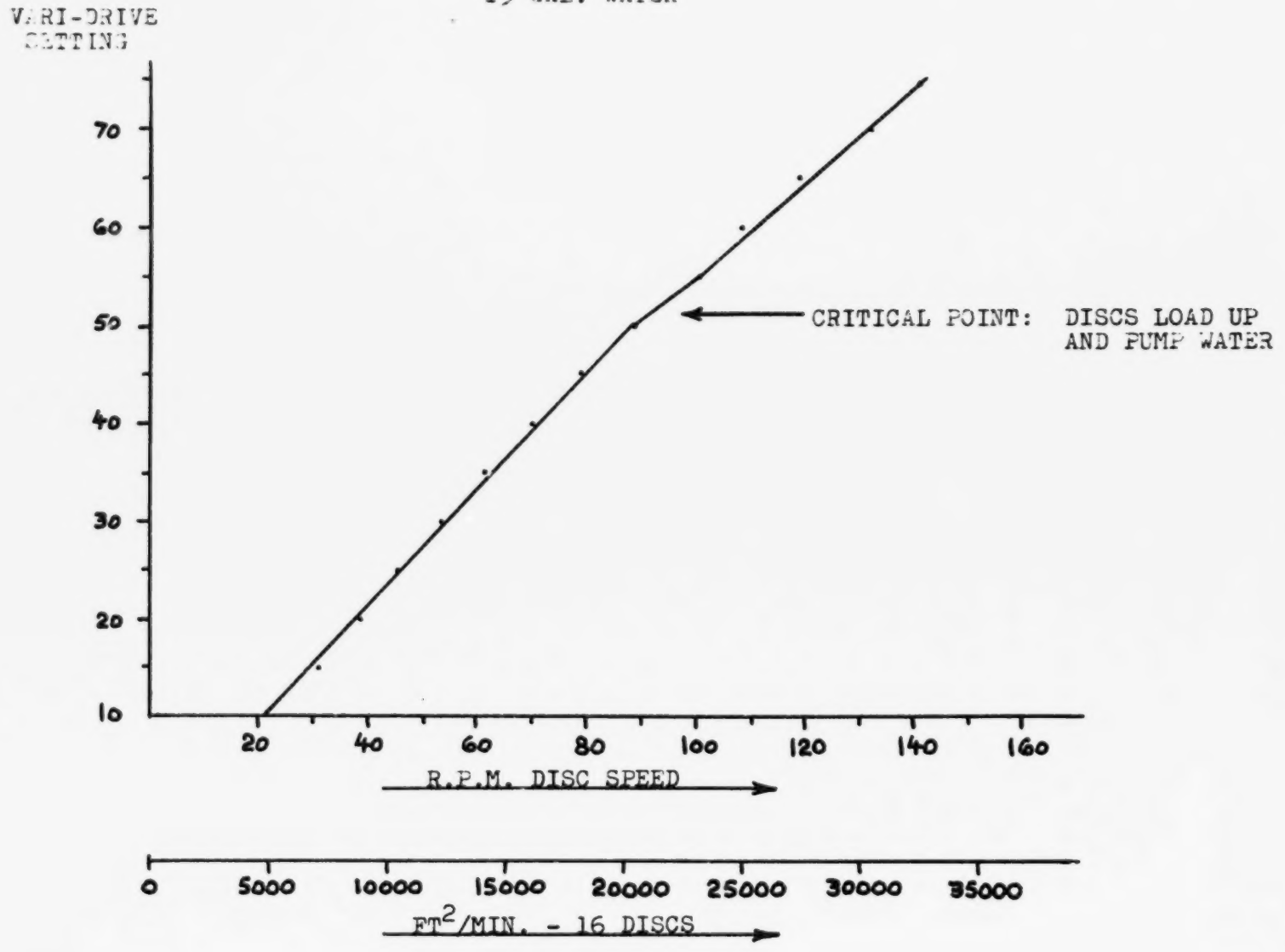


FIG. #12

TABLE #2

TWO PHASE CONTACTOR – #40 CHAIN DRIVE

CONTACT AREA (ft^2/min.) VERSUS DISC R.P.M.

Date 4-4-68

Area per disc = 7.22 ft^2 one side.
Area for 16 discs = 231.06 ft^2.

Area per disc = 14.44 ft^2 two sides
Area for 20 discs = 288.82 ft^2

VARI–DRIVE SETTING	DISC R.P.M.	EXTRACTION SECTION 16 DISCS FT^2 / MIN	EXTRACTION & DEMISTER 20 DISCS FT^2 / MIN	
10	22	5,080	6,350	
15	31	7,160	8,950	
20	37	8,550	10,700	
25	45	10,400	13,000	
30	53	12,250	15,300	NO CARRY OVER 16 DISCS WET
35	61	14,100	17,600	
40	70	16,200	20,200	
45	79	18,300	22,800	
50	86	19,900	24,800	CRITICAL APEA. WATER PUMPING (1)
55	101	23,300	29,200	
60	108	25,000	31,200	
65	120	27,700	34,700	
70	133	30,700	38,400	
75	141	32,600	40,700	

(1) Note: Above this critical area, water is withheld in disc holes in such quantities that rapid entrainment takes place.

LOCATION AND FLOW ARRANGEMENTS

Recirculation pump plumbing was so arranged that pump discharge was either to inlet end or discharge end of the two phase contactor, Fig. #3. In the latter case, the concentrated chemical will be in contact with the lowest concentration of hydrogen sulfide (counter-current operation). Total volume of solution in holding tank and contactor can be varies from 20 to 50 gal.

CONSTRUCTION MODIFICATION

After several weeks of operation with the two-phase contactor, provisions were made to install 9 sampling ports at the following locations: Three ports on top of contactor, three on back of contactor and three on front of contactor. These ports were used to inspect the inside of two phase contactor, as openings to setup sprays inside contactor, and as possible surface sampling locations.

DETERMINATION OF OXYGEN MASS TRANSFER RATE

Mass transfer rates express the ability of a unit to complete chemical reactions, and are a function of the contact area exposed per minute. References (7), (8), (9).

Experiments set up to show deoxygenation of tap water with an intended low hydrogen sulfide concentration in foul air were inconclusive - probably due to simultaneous reoxygenation.

Using the completed two phase liquid-gas contactor, a series of tests were performed on tap water with dissolved oxygen removed by overnight treatment with sodium sulfite. Re-oxygenation of the solution (50 gal. volume-recirculated) from 0.0 to 8.0 PPM dissolved oxygen occurred in 90 sec. at a disc speed of 53 R.P.M. (12,250 ft. ^{2}/min.).

The peak oxygen transfer varied directly with the disc speed, corresponding to increase in total contact area. See Table #3. At higher disc R.P.M. the 50 gal. of de-oxygenated tap water was re-oxygenated at too rapid a rate for sampling, that is,

0.0 to 8.0 PPM dissolved oxygen in less than 60 sec. See Fig. #13 and #14. Peak oxygen transfer is in excess of 600 milligrams of oxygen per minute recorded at 53 R.P.M. disc speed or 12,250 ft. ^{2}/min. contact area, under the following conditions:

> Fifteen gal. initially de-oxygenated water, static run (no air flow through contactor and no water recirculation) and 22°C ambient temperature. The oxygen mass transfer rate drops off rapidly as the saturation point of the water, with respect to dissolved oxygen, is reached.

TABLE #3
TOTAL OXYGEN TRANSFER RATE
TWO PHASE CONTACTOR – NO AIR FLOW–NO LIQUID RECIRCULATION
CONTACT AREA VARIED
15 GAL. DE–OXYGENATED WATER IN CONTACTOR (5-9-68)

TOTAL OXYGEN TRANSFER OF CONTACTOR – ACCUMULATIVE TOTAL

CONTACT TIME MINUTES	22 R.P.M. 5,083 ft^2/min. mg. Oxygen	37 1/2 R.P.M. 8,665 ft^2/min. mg. Oxygen	53 R.P.M. 12,246 ft^2/min. mg. Oxygen
.0	0	0	34.0
0.5	0	102.0	294.8
1.0	28.3	255.1	402.6
1.5	96.4	323.2	430.7
2.0	153.1	368.6	436.6
3.0	218.3	408.2	436.6
4.0	283.5	413.9	439.4
6.0	351.5	419.6	442.3
TOTAL AVERAGE mg/min.	58.6	69.8	73.7

Oxygen Transfer – mg oxygen/ft^2/min. each min.

TIME INTERVAL MINUTES	22 R.P.M. 5083 ft^2/min.	37 1/2 R.P.M. 8665 ft^2/min.	53 R.P.M. 12246 ft^2/min.
0 – 0.5	0	0.0232	0.0476
0.5 – 1.0	0.0110	0.0350	0.0174
1.0 – 1.5	0.0266	0.0156	0.0026
1.5 – 2.0	0.0220	0.0104	0.0010
2.0 – 3.0	0.0127	0.0045	0.0000
3.0 – 4.0	0.0127	0.0007	0.0001
4.0 – 6.0	0.0067	0.0003	0.0001

mg. oxygen/minute/two phase contractor

TIME INTERVAL MINUTES	22 R.P.M. 5,083 ft^2/min. mg. Oxygen/min.	37 1/2 R.P.M. 8,665 ft^2/min. mg. Oxygen/min.	53 R.P.M. 12,246 ft^2/min. mg. Oxygen/min.
0 – 0.5	0	201.0	582.9
0.5 – 1.0	55.9	303.0	213.1
1.0 – 1.5	135.2	135.2	31.8
1.5 – 2.0	111.8	90.1	12.2
2.0 – 3.0	64.6	39.0	0.0
3.0 – 4.0	64.6	6.1	1.2
4.0 – 6.0	34.1	2.6	1.2
6 Min. – Rate Average	66.6	111.0	120.3

2 PHASE CONTACTOR
OXYGEN TRANSFER - 16 DISCS

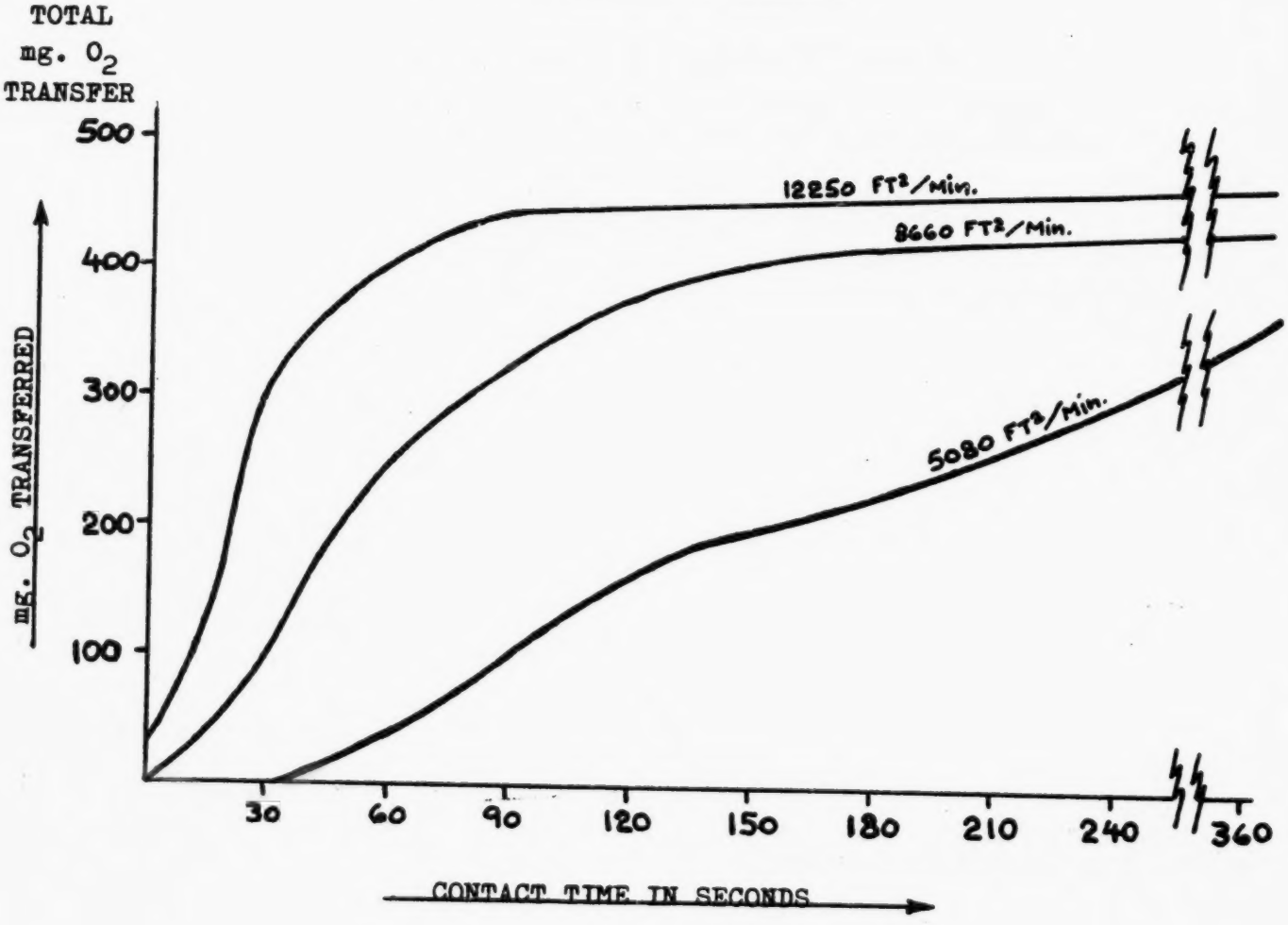


FIG. #13

2 PHASE CONTACTOR

OXYGEN TRANSFER RATES

16 DISCS

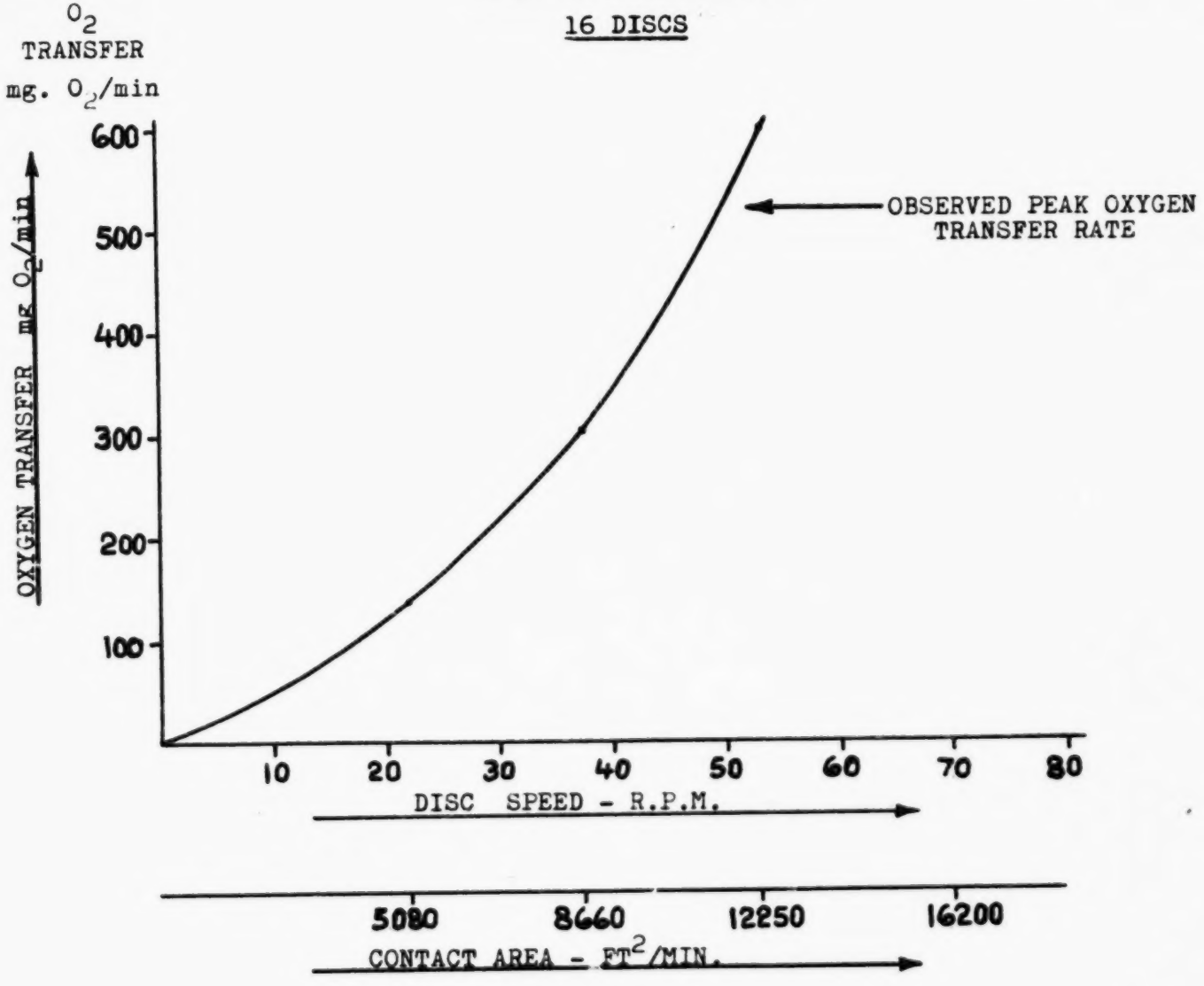


FIG. #14

SECTION 7 - DISCUSSION

BACKGROUND OF STUDY METHODS

Removal of Hydrogen Sulfide was the basic parameter considered, and in all of the following studies, monitoring of H_2S in input foul air and treated discharged air was accomplished by means of two "A.I.S.I." (lead acetate paper tape) samplers and recorders. (10). See Fig. 15.

An attempt to evaluate odor of discharged air was made by Waste Water Treatment Plant personnel, during each run. No formal odor panel was used, except to weekly evaluate odor levels. Thus, a particular obnoxious odor not caused by Hydrogen Sulfide could be detected, if caused by interreacting chemicals in the two phase contactor.

The standardization of the A.I.S.I. H_2S sampler and recorder was carried out by using a H_2S/air mixture of known H_2S concentration. This H_2S/air mixture was prepared as follows:

A known volume of pure H_2S gas was mixed with fresh air in a mylar-lined polyethylene plastic bag, an aliquot of the mixture taken and the H_2S in it fixed by means of a zinc acetate solution. Then by iodometric methods, the sulfides present were found (treatment of the sulfide absorbing solution with excess iodine and back-titration with sodium thiosulfate to the starch endpoint). (11).

This procedure was adopted by Hyperion Plant (City of Los Angeles) methods - Mr. Frank Wada, Chemist. A cross-checking of Hydrogen Sulfide levels was accomplished with two "Barton" titrators. One on loan from the City of Los Angeles, Hyperion Sewage Treatment Plant, (12), and the other by Dr. Austin of Barton Industries Division, I.T.T.

FIG. =15
A.I.S.I HYDROGEN SULFIDE SAMPLER AND RECORDER

During the experimental runs, continuous monitoring of the following variables was recorded:

Air input and discharge flows.
Air input and discharge temperatures.
Air input and discharge % relative humidity.
Liquid recirculation temperatures.
Liquid levels of the Contactor and Demister sections.
R.P.M. disc speed (contact area/minute.)
Liquid recirculation pressures.
A.I.S.I. input and discharge sulfide levels.
Operator nasal monitoring of odor of discharged air.
Sampling of reactive liquid and/or air for reactants, i.e., Chlorine, Ozone, Sulfates, etc.
pH, alkalinity, copper and solvents were determined during specific runs.

pH and alkalinity of absorbing solution were monitored with the following instruments: The pH with a portable Orion pH meter, and the alkalinity with a Beckman automatic Titrator.

DETAILS OF RUNS

The most common conditions under which the runs were carried out, are shown below.

Input H_2S 1.0 to 15.0 ppm.
200 - 1,000 C.F.M. foul air input to two phase contactor.
15 - 20 gal. solution in two phase contactor, with the solution recirculated and sprayed into contactor by means of two spray nozzles located just above foul air input to contactor.

Contact Area: 15,000 Ft.^{2}/min. (16 discs at 65 R.P.M.) and
18,800 Ft.^{2}/min. (20 discs at 65 R.P.M.)

Limitations of contactor with use have determined that 1,000 C.F.M. is the maximum volume of foul air that can be treated effectively with a 15 - 10 gal. reagent solution in the contactor. Residence time is insufficient at high air flows when absorbing chemicals are slow reacting. (See potassium permanganate runs). 65 R.P.M. disc speed (or 15,000 Ft.^{2}/min. contact area - 16 discs) is the maximum safe rotation speed with 20 gal. of liquid in contactor.

For calibration of A.I.S.I. meter, the procedure was:

a) Read out comparison against a standard tape.

b) By actual titration: absorbing a mixture of H_2S and air into a zinc acetate solution, and then finding H_2S by iodometry. Once the H_2S concentration is calculated, use it to calibrate the A.I.S.I. meters.

c) Cross checking against a "Barton Titrator" for Hydrogen Sulfide levels, with Draeger tubes used to determine the general range of sulfide concentration.

References: See (7), (8), (9), (10), (11), (12) in Bibliography.

TAP WATER AND pH ADJUSTED TAP WATER

To determine at what foul air flow levels hydrogen sulfide removal takes place, and at what rate using tap water as the liquid reactant, low foul air flows of 100 C.F.M., 200 C.F.M. and 400 C.F.M. were used to perform a series of duplicate runs.

Typical tap water analyses are shown in Table #4, #5, #6 and #7.

Total hydrogen sulfide removal in tap water was disappointingly small and would require large amounts of tap water. Table #8 and Fig. #16. With pH - adjusted (using caustic soda) tap water, Table #9, the H_2S removal was small. However, increased removal did take place at pH = 11.0. See Fig. #17, #18, #19.

There was considerable variation at this time in duct foul air levels of H_2S, and a standard hydrogen sulfide gas cylinder was supplemented to standardize the H_2S feed to contactor.

TABLE #4

CITY OF SAN DIEGO

UTILITIES DEPARTMENT WATER LABORATORY

CONSTITUENT:	MILLIGRAMS PER LITER	GRAINS PER GALLON
Silica (SiO_2)	8.8	0.51
Iron (Fe)	0.04	0.00
Aluminum (Al)	– –	– –
Manganese (Mn)	0.0	0.0
Calcium (Ca)	78.0	4.56
Magnesium (Mg)	28.0	1.64
Sodium (Na)	110.0	6.42
Potassium (K)	7.0	0.41
Carbon Dioxide (CO_2)	1.6	0.09
Carbonate (CO_3)	0.0	0.0
Bicarbonate (HCO_3)	153.0	8.94
Total alkalinity as $CaCO_3$	125.0	7.30
Sulfate (SO_4)	280.0	16.35
Chloride (Cl)	99.0	5.78
Nitrate (NO_3)	0.02	0.0
Fluoride (F)	0.42	0.02
Phosphate (PO_4) Poly 0.0 Ortho 0.58	Total 0.58	0.03
Total hardness as $CaCO_3$	311.0	18.16
Carb hardness as $CaCO_3$	125.0	7.30
Non carb hardness as $CaCO_3$	186.0	10.86
Total solids	702.0	41.00
Turbidity	0.45	0.03
Conductivity (10^{-6})	1,005.0	
pH	8.2	
pHs	7.71	
Langelier index	0.49	
Ryznar Index	7.22	

REACTING VALUES:	MILLIGRAM EQUIVALENTS
Calcium (rCa)	3.8922
Magnesium (rMg)	2.3016
Sodium (rNa)	4.7850
Potassium (rK)	0.1792
Carbonate (rCO_3)	0.0
Bicarbonate ($rHCO_3$)	2.5092
Sulfate (rSO_4)	5.8240
Chloride (rCl)	2.8017
Nitrate (rNO_3)	0.0002
Fluoride (rF)	0.0221
Concentration Value	22.3152

CHARACTER FORMULA	PER CENT
Calcium (rCa)	17.44
Magnesium (rMg)	10.31
Sodium (rNa)	21.44
Potassium (rK)	0.80
Carbonate (rCO_3)	0.0
Bicarbonate ($rHCO_3$)	11.24
Sulfate (rSO_4)	26.10
Chloride (rCl)	12.56
Nitrate (rNO_3)	0.0
Fluoride (rF)	0.10
% Na	44 49

CHEMICAL ANALYSIS OF **ALVARADO EFFLUENT** ..... Sampled: May, 1968 – Composite

TABLE #5

CITY OF SAN DIEGO

UTILITIES DEPARTMENT WATER LABORATORY

CONSTITUENT	MILLIGRAMS PER LITER	GRAINS PER GALLON
Silica (SiO_2)	11.0	0.64
Iron (Fe)	0.03	0.0
Aluminum (Al)	—	—
Manganese (Mn)	0.0	0.0
Calcium (Ca)	83.0	4.85
Magnesium (Mg)	28.0	1.64
Sodium (Na)	115.0	6.72
Potassium (K)	7.2	0.42
Carbon Dioxide (CO_2)	1.6	0.09
Carbonate (CO_2)	0.0	0.0
Bicarbonate (HCO_3)	151.0	8.82
Total alkalinity as $CaCO_3$	124.0	7.24
Sulfate (SO_4)	321.0	18.75
Chloride (Cl)	108.0	6.31
Nitrate (NO_3)	0.02	0.0
Fluoride (F)	0.47	0.03
Phosphate (PO_4) poly 0.02 Ortho 0.25	Total 0.27	0.01
Total hardness as $CaCO_3$	323.0	18.86
Carb hardness as $CaCO_3$	124.0	7.24
Non carb hardness as $CaCO_3$	199.0	11.62
Total solids	729.0	42.57
Turbidity	0.4	0.02
Conductivity (10^{-6})	1,038.0	
pH	8.2	
pHs	7.69	
Langelier Index	0.51	
Ryznar Index	7.18	

REACTING VALUES:	MILLIGRAM EQUIVALENTS
Calcium (rCa)	4.1417
Magnesium (rMg)	2.3016
Sodium (rNa)	5.0025
Potassium (rK)	0.1843
Carbonate (rCO_3)	0.0
Bicarbonate ($rHCO_4$)	2.4764
Sulfate ($_rSO_3$)	6.6768
Chloride ($_rCl$)	3.0564
Nitrate (rNO_3)	0.0003
Fluoride (rF)	0.0247
Concentration Value	23.8647

CHARACTER FORMULA	PER CENT
Calcium (rCa)	17.35
Magnesium (rMg)	9.64
Sodium (rNa)	20.96
Potassium (rK)	0.77
Carbonate (rCO_3)	0.0
Bicarbonate ($rHCO_3$)	10.38
Sulfate (rSO_4)	27.98
Chloride (rCl)	12.81
Nitrate (rNO_3)	0.0
Fluoride (rF)	0.10
% Na	44.60

CHEMICAL ANALYSIS OF **ALVARADO EFFLUENT**..... Sampled: June, 1968 - Composite

TABLE # 6

CITY OF SAN DIEGO
UTILITIES DEPARTMENT WATER LABORATORY

CONSTITUENT:	MILLIGRAMS PER LITER	GRAINS PER GALLON
Silica (SiO_2)	9.2	0.54
Iron (Fe)	0.04	0.00
Aluminum (Al)	0.01	0.00
Manganese (Mn)	0.0	0.00
Calcium (Ca)	88.0	5.14
Magnesium (Mg)	31.0	1.81
Sodium (Na)	116.0	6.78
Potassium (K)	8.0	0.47
Carbon Dioxide (CO_2)	1.16	0.07
Carbonate (CO_3)	0.0	0.00
Bicarbonate (HCO_3)	151.0	8.82
Total alkalinity as $CaCO_3$	124.0	7.24
Sulfate (SO_4)	295.0	17.23
Chloride (Cl)	102.0	5.96
Nitrate (NO_3)	0.35	0.02
Fluoride (F)	0.30	0.02
Phosphate (PO_4) Poly 0.02 Ortho 0.53	Total 0.55	0.03
Total hardness as $CaCO_3$	350.0	20.44
Carb hardness as $CaCO_3$	124.0	7.24
Non carb hardness as $CaCO_3$	226.0	13.20
Total solids	806.0	47.07
Turbidity	0.7	
Conductivity (10^{-6})	1,142.0 @ 24° C	
pH	8.2	
pHs	7.66	
Langelier Index	0.54	
Ryznar Index	7.12	

REACTING VALUES:	MILLIGRAM EQUIVALENTS
Calcium (rCa)	4.3712
Magnesium (rMg)	2.5843
Sodium (rNa)	5.0460
Potassium (rK)	0.2048
Carbonate (rCO_3)	0.0000
Bicarbonate ($rHCO_3$)	2.4809
Sulfate (rSO_4)	6.1360
Chloride (rCl)	2.8866
Nitrate (rNO_3)	0.0056
Fluoride (rF)	0.0157
Concentration Value	23.7311
CHARACTER FORMULA	**PER CENT**
Calcium (rCa)	18.41
Magnesium (rMg)	10.88
Sodium (rNa)	21.26
Potassium (rK)	0.86
Carbonate (rCO_3)	0.00
Bicarbonate ($rHCO_3$)	10.45
Sulfate (rSO_4)	25.85
Chloride (rCl)	12.16
Nitrate (rNO_3)	0.02
Fluoride (rF)	0.06
% Na	43.01

CHEMICAL ANALYSIS OF **COLORADO RIVER WATER AQUEDUCT #1** ..... Sampled: March 30, 1970

TABLE #7

CITY OF SAN DIEGO

UTILITIES DEPARTMENT WATER LABORATORY

CONSTITUENT:	MILLIGRAMS PER LITER	GRAINS PER GALLON
Silica (SiO_2)	9.8	0.57
Iron (Fe)	0.10	0.00
Aluminum (Al)	0.04	0.00
Manganese (Mn)	0.0	0.00
Calcium (Ca)	89.0	5.19
Magnesium	26.0	1.51
Sodium (Na)	114.0	6.65
Potassium (K)	8.3	0.48
Carbon Dioxide (CO_2)	1.46	0.08
Carbonate (CO_3)	0.0	0.00
Bicarbonate (HCO_3)	151.0	8.81
Total alkalinity as $CaCO_3$	124.0	7.24
Sulfate (SO_4)	289.0	16.87
Chloride (Cl)	107.0	6.24
Nitrate (NO_3)	0.55	0.03
Fluoride (f)	0.44	0.02
Phosphate (PO_4) Poly 0.25 Ortho 0.10	Total 0.35	0.02
Total hardness as $CaCO_3$	332.0	19.38
Carb hardness as $CaCO_3$	124.0	7.24
Non carb hardness as $CaCO_3$	208.0	12.14
Total solids	807.0	47.12
Turbidity	1.5	
Conductivity (10^{-6})	1,153.0 @ 22° C	
pH	8.1	
pHs	7.76	
Langelier Index	0.34	
Ryznar Index	7.42	

REACTING VALUES:	MILLIGRAM EQUIVALENTS
Calcium (rCa)	4.4311
Magnesium (rMg)	2.1700
Sodium (rNa)	4.9590
Potassium (rK)	0.2124
Carbonate (rCO_3)	0.0000
Bicarbonate ($rHCO_3$)	2.4809
Sulfate ($_rSO_4$)	6.0112
Chloride ($_rCl$)	3.0281
Nitrate (rNO_3)	0.0088
Fluoride (rF)	0.0231
Concentration Value	23.3246

CHARACTER FORMULA	PER CENT
Calcium (rCa)	18.99
Magnesium (rMg)	9.30
Sodium (rNa)	21.26
Potassium (rK)	0.91
Carbonate (rCO_3)	0.00
Bicarbonate ($rHCO_3$)	10.63
Sulfate (rSO_4)	25.77
Chloride (rCl)	12.98
Nitrate (rNO_3)	0.03
Fluoride (rF)	0.09
% Na	43.92

CHEMICAL ANALYSIS OF **COLORADO RIVER WATER AQUEDUCT #2** ..... Sampled March 3, 1970

TABLE #8

H_2S REMOVAL WITH TAP WATER – 100 C.F.M., 200 C.F.M., 400 C.F.M. FOUL AIR

15 GAL. TAP WATER IN CONTACTOR – NO RECIRCULATION

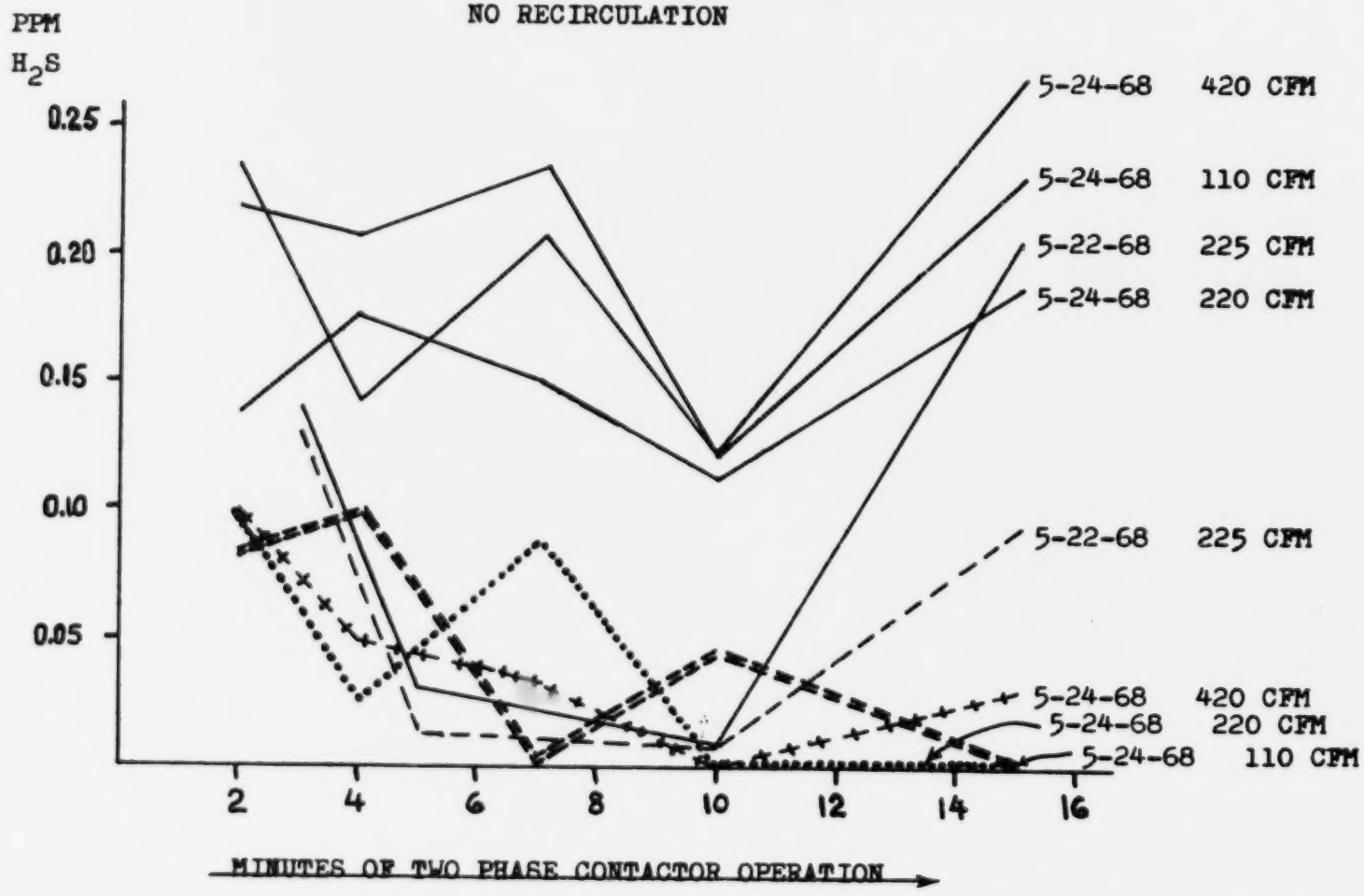
12,250 FT^2/MIN CONTACT AREA (16 DISCS AT 53 R.P.M.)

DATE	AIR FLOW STD CFM	RESIDENCE TIME SECONDS	LENGTH OF RUN MIN.	H_2S INPUT PPM	H_2S REMOVED PPM	%	pH START	pH END	DISSOLVED OXYGEN START	DISSOLVED OXYGEN END	DISSOLVED SULFIDES (1) START	DISSOLVED SULFIDES (1) END	TOTAL ALKALINITY START	TOTAL ALKALINITY END
5-22-68	150	6.2	18	0.65	0.10	16.	8.5	8.5	8.6	9.2	0.0	0.0	132	132
5-22-68	225	12.5	15	0.12	0.09	75.	8.5	8.5	8.6	9.2	0.0	0.0	132	132
5-24-68	420	6.6	15	0.21	0.05	24.	8.4	8.4	7.2	9.2	0.0	0.0	132	134
5-24-68	220	12.7	15	0.18	0.05	30.	8.4	8.4	7.7	8.4	0.0	0.0	134	134
5-24-68	110	23.6	15	0.17	0.05	32.	8.4	8.4	7.6	8.9	0.0	0.0	134	134

(1) Pomeroy method

NOTES: Overall input air temperature range was 17.5° C to 23.2° C. Average Per Cent Relative Humidity (% R.H.): Contactor input 68%, contactor discharge 89%

H_2S REMOVAL WITH TAP WATER
100; 200; 400 C.F.M. FOUL AIR
CONTACT AREA: 12250 FT^{2}/MIN
15 GAL. TAP WATER IN CONTACTOR
NO RECIRCULATION



——— SOLID LINE = PPM H_2S INPUT
DOTTED LINES = PPM H_2S REMOVED

FIG. #16

TABLE #9

15 GAL. pH–ADJUSTED TAP WATER IN CONTACTOR – NO RECIRCULATION
12250 FT^2/MIN CONTACT AREA (16 DISCS AT 53 R.P.M.)

200 CFM, 400 CFM, 600 CFM pH = 9.0, 10.0, 11.0 (1)

DATE	AIR FLOW STD CFM	AIR RESI DENCE TIME SECONDS	LENGTH OF RUN MIN.	H_2S INPUT PPM	H_2S REMOVED PPM	H_2S REMOVED %	ML 50% NaOH LYE ADDED TO 50 GAL WATER	pH START	pH END	DISSOLVED OXYGEN START	DISSOLVED OXYGEN END	DISSOLVED SULFIDES (1) START	DISSOLVED SULFIDES (1) END	TOTAL ALKALINITY START	TOTAL ALKALINITY END
5-27-68	200	14.0	15	0.10	0.03	28.0	3.0	9.0	8.70	7.2	9.2	0.0	0.0	149	
5-28-68	225	12.4	15	0.32	0.05	14.	3.0	9.2	8.65	7.55	8.95	0.0	0.3	187	173
6-10-68	205	13.6	30	0.37	0.30	82.	36.0	10.8	9.45	8.5	8.5	0.0	1.2	136	127
5-27-68	420	6.7	15	5.90	1.69	29.	3.0	9.0	8.55	7.7	8.4	0.0	1.5	144	
5-27-68	415	6.8	15	0.16	0.05	29.	3.0	9.0	8.70	7.6	8.9	0.0	0.0	148	
5-28-68	420	6.7	15	0.19	0.03	17.	19.0	9.9	8.10	7.6	8.8	0.0	0.5	146	99
6-12-68	410	6.9	30	0.62	0.22	36.0	37.0	10.65	9.35	8.1	8.3	0.0	1.5	149	132
6-3-68	660	4.3	15	0.30	0.14	48.	3.0	9.0	8.40	8.0	9.35	0.0	0.15	144	145
6-3-68	655	4.4	15	0.59	0.15	25.	13.0	9.05	8.80	8.2	8.85	0.0	0.9	97	128
6-7-68	660	4.3	30	1.33	0.52	39.	36.0	10.9	9.45	8.3	7.75	0.0	5.0	137	128

(1) pH was adjusted with caustic soda

(2) Pomeroy method 4-30-68

NOTES: Overall input air temperature range was 17.5° C to 23.2° C.
Average Per Cent Relative Humidity (% R.H.) was:
Contactor input 80%, contactor discharge 93%.

H_2S REMOVAL WITH pH ADJUSTED TAP WATER
200 C.F.M. FOUL AIR
CONTACT AREA: 12250 FT^2/MIN
15 GAL. SOLUTION IN CONTACTOR
NO RECIRCULATION
pH= 9.0, 9.2

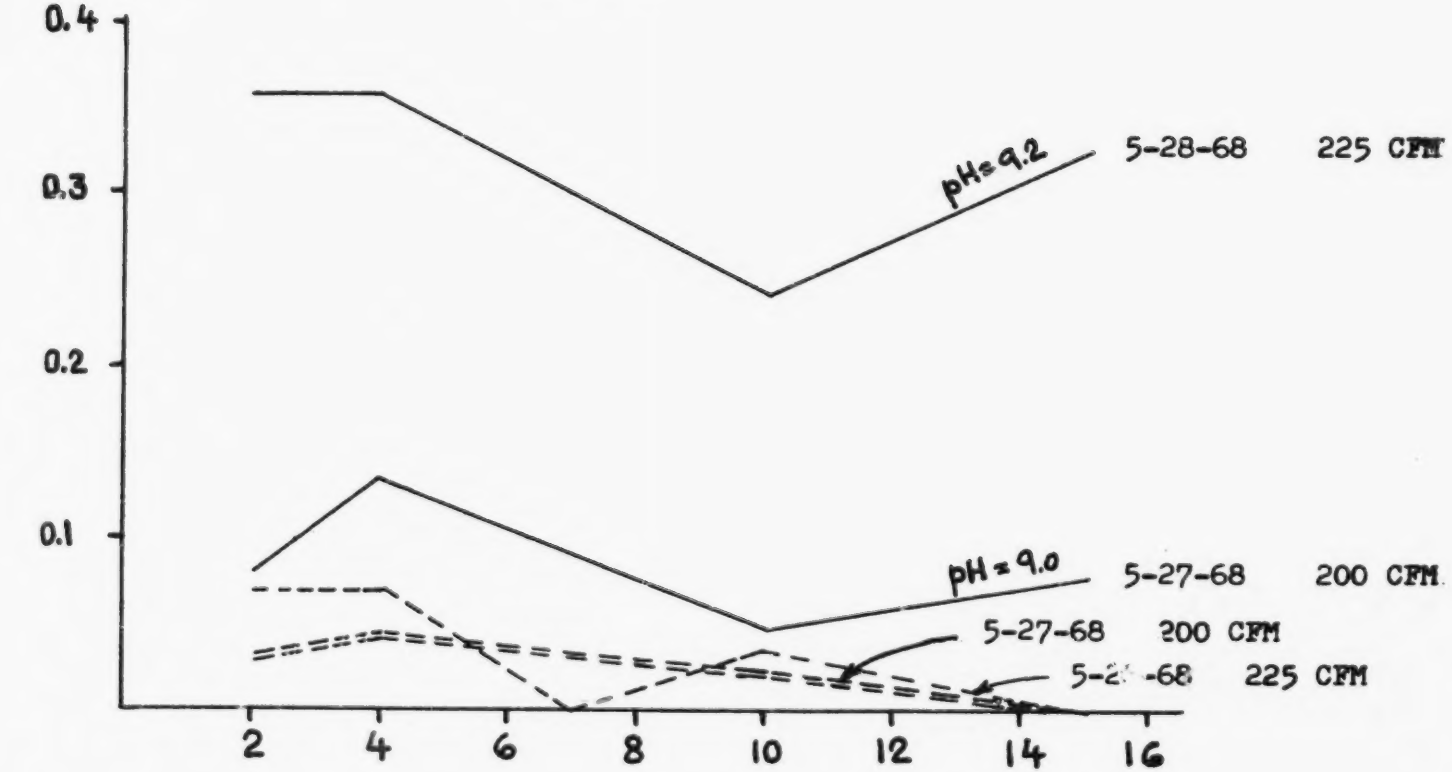


FIG. #17

H_2S REMOVAL WITH pH ADJUSTED TAP WATER
400 C.F.M.. FOUL AIR
CONTACT AREA: 12250 FT^2/MIN
15 GAL. SOLUTION IN CONTACTOR
NO RECIRCULATION
pH= 10.65

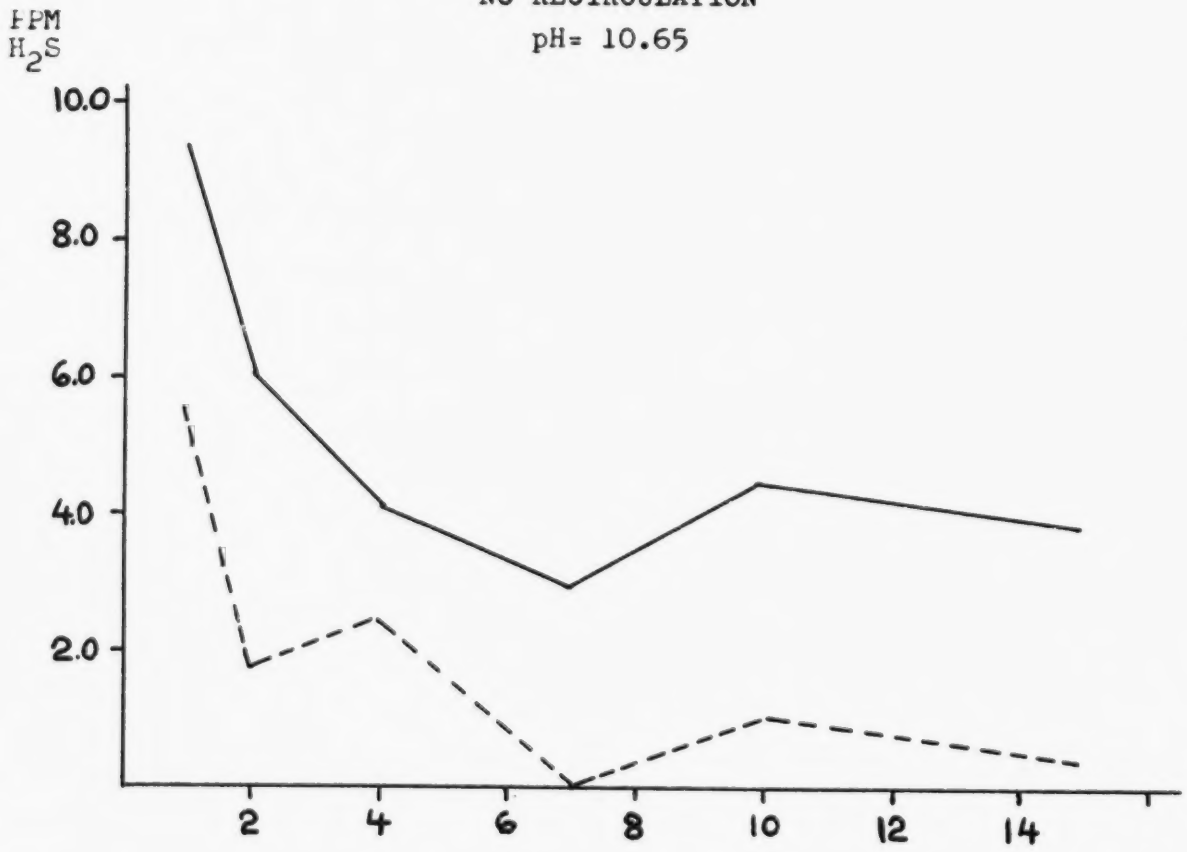


FIG. #

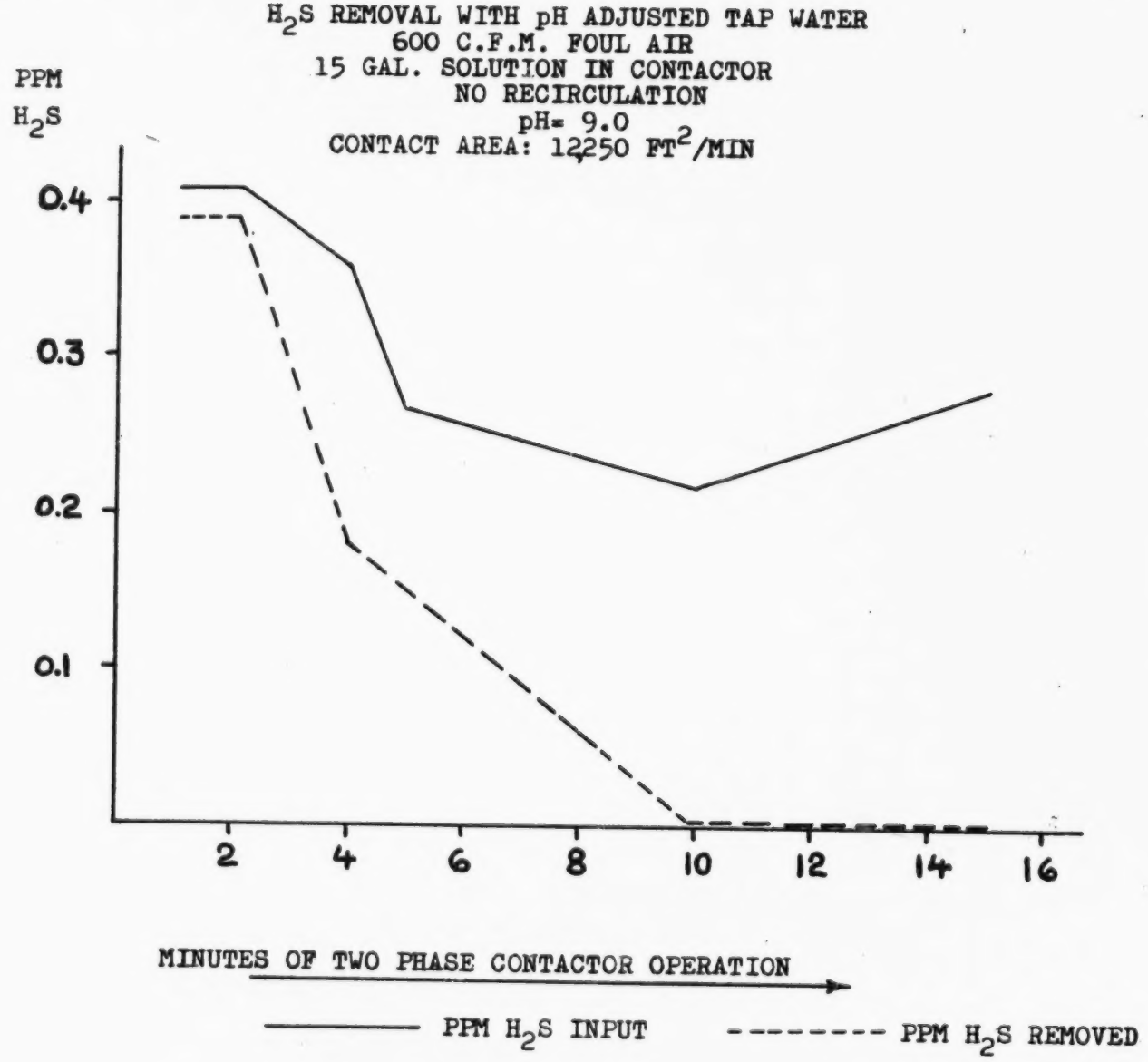

H_2S REMOVAL WITH pH ADJUSTED TAP WATER
600 C.F.M. FOUL AIR
15 GAL. SOLUTION IN CONTACTOR
NO RECIRCULATION
pH= 9.0
CONTACT AREA: 12250 FT^2/MIN
PPM
H_2S
0.4
0.3
0.2
0.1
2
4
6
8
10
12
14
16
MINUTES OF TWO PHASE CONTACTOR OPERATION
PPM H_2S INPUT
PPM H_2S REMOVED

FIG. #19

CAUSTIC SODA (TECHNICAL SODIUM HYDROXIDE)

A series of experimental runs with varying concentrations of commercial (50%) caustic soda as the reactant in the two phase contactor were scheduled. (6). Original plans called for varying the caustic soda concentration from 1% to 10% in water solution. Excessive foam entrainment resulted with caustic soda concentrations above 0.1%. Short experimental runs at caustic soda levels of 0.25% and 1.0% demonstrated removal exceeding 95% with input levels of 1.3 to 2.8 PPM H_2S and air flow of 800 C.F.M. See Table #10 and Fig. #20.

This method seems to warrant additional investigation. A demister to remove the caustic soda could be used as a second stage extractor. Also, the possibility of the use of de-foaming agents should be investigated.

Reference: See (6) in Bibliography.

TABLE #10

H_2S REMOVAL WITH 50 GAL. TOTAL VOLUME OF CAUSTIC SODA, 15 GAL. IN CONTACTOR

DATE	CAUSTIC SODA %	AIR FLOW CFM	TEMP INPUT AIR °C	AIR RESI-DENCE TIME SECONDS	CON-TACT AREA FT^2/MIN.	LENGTH OF RUN MIN.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	pH START	pH END	PPM TOTAL ALKALINITY START	PPM TOTAL ALKALINITY END	REMARKS
4-22-68	1.0	710	22.6	3.9	23,100	45	1.60	1.57	98.0	12.8	12.8	17,950	17,100	Foamed
4-24-68	0.25	830	23.5	3.4	20,200	145	6.60	6.47	98.0	12.6	12.6	4,390	4,460	Foamed Evaporation Loss
4-25-68	0.1	750	22.4	3.6	22,800	70	2.88	2.35	82.0	12.4	12.1	1,940	2,030	Some Foam - Evaporation Loss
4-26-68	0.1	760	21.3	3.6	23,100	120	1.78	1.42	80.0	12.3	11.55	1,640	1,630	Some Foam
4-30-68	0.1	930	20.4	3.0	12,250	210	2.67	1.71	64.0	12.6	12.55	2,210	3,820	Evaporation Loss

NOTES: At caustic soda levels of 1.0% and 0.25% low and intermitent recirculation due to foamy conditions. Estimated recirculation volume: 1.0 Gal./Min., or less.

At caustic soda level of 0.1%, Recirculation flow was 15 G.P.M.

Overall input air average temperature was 22.0° C. (72.0° F).

Average Per Cent Relative Humidity (% R.H.) was: Contactor input 91%, Contactor discharge 98%

DETERMINATION OF H_2S REMOVAL WTTH SODIUM HYDROXIDE SOLUTION
(CAUSTIC SODA)

pH= 12.0 to 12.8
ABOUT 700; 800 and 900 C.F.M. AIR FLOW

15 GAL. NaOH SOLUTION IN CONTACTOR (50 GAL. RECIRCULATED TANK SOLUTION)
INPUT H_2S RANGE: 1.60 to 2.80 PPM - 53, 70 AND 80 R.P.M. DISC SPEED

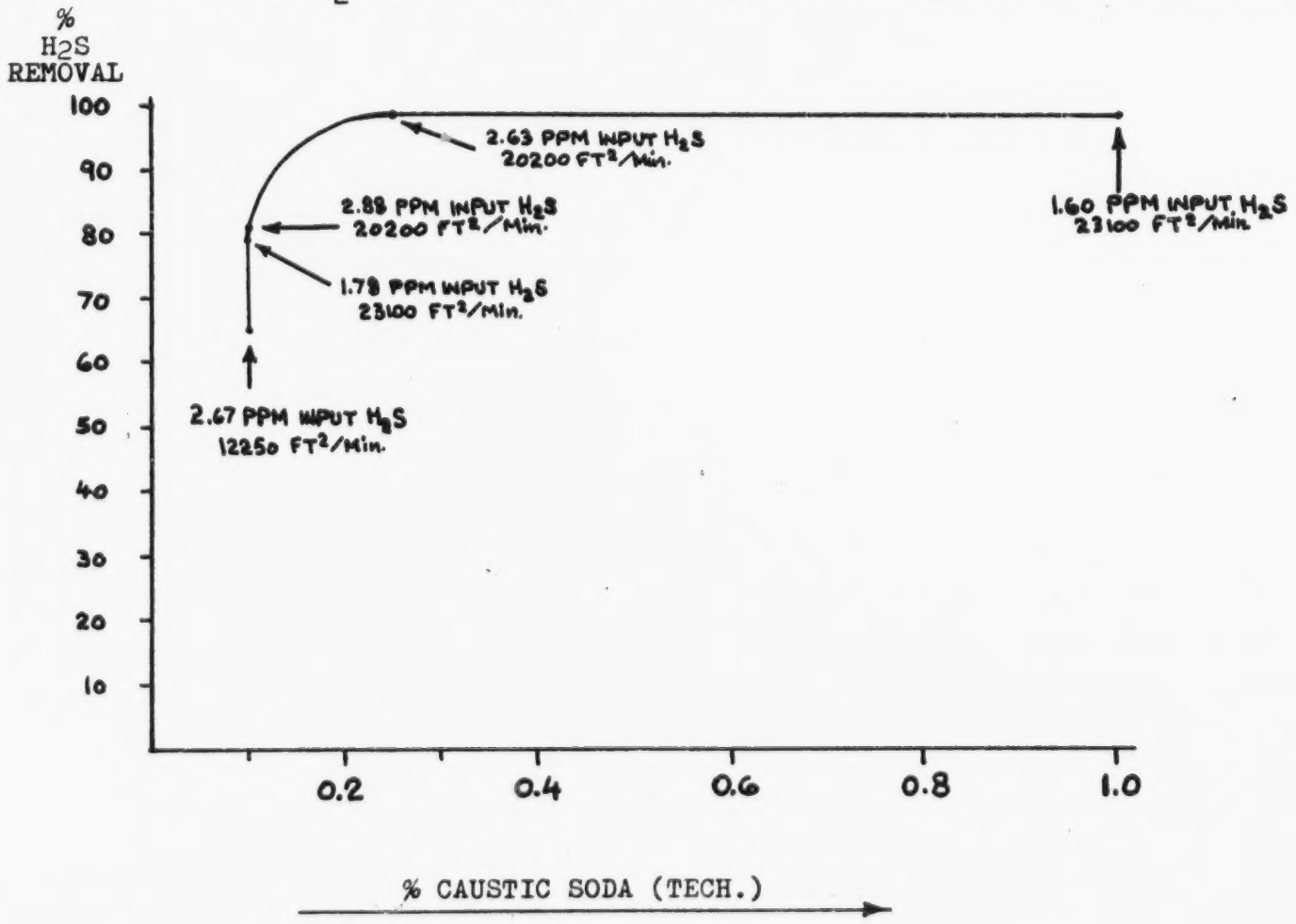


FIG. #20

CALCIUM HYPOCHLORITE

To determine hydrogen sulfide removal, tentative runs using less than 1%, 1% and 2% calcium hypochlorite were performed at initial pH values varied from pH of 10.0 to pH of 12.0.

The range of available chlorine residual was varied from 100 ppm to 20,000 ppm. The chlorine residual was determined by the iodometric method. The range of alkalinity was 30 ppm to 15,000 ppm as $CaCO_3$. The foul air flow was maintained at 400 C.F.M., with a residence time of over 6 seconds.

Average H_2S removal was 50 - 80% on inputs of 3 to 10 ppm of hydrogen sulfide. See Tables #11, #12 and Fig. #21 and #22.

References: See (5), (11), (16) in Bibliography.

TABLE #11

H_2S REMOVAL WITH CALCIUM HYPOCHLORITE AT 100 PPM; 200 PPM and 400 PPM AVAILABLE CHLORINE RESIDUAL – 15 GAL. SOLUTION IN CONTACTOR – NO SOLUTION RECIRCULATION – 12,250 FT^2/MIN. CONTACT AREA

DATE	AIR FLOW S.T.D. CFM	INPUT AIR TEMP. °C	AIR RESI-DENCE TIME SECONDS	LENGTH OF RUN MIN.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	pH START	pH END	PPM DISSOLVED SULFIDES START	PPM DISSOLVED SULFIDES END	PPM CHLORINE IN THE SOLUTION START	PPM CHLORINE IN THE SOLUTION END	PPM TOTAL ALKALINITY START	PPM TOTAL ALKALINITY END
6-14-70	410	17.7	6.9	30	0.55	0.21	38.0	11.3	8.9	0.0	0.0	374	321	37	428
6-14-70	410	21.1	6.9	30	0.24	0.10	42.0	11.2	8.75	0.0	0.0	207	158	243	288
6-18-70	415	18.0	6.8	30	0.78	0.28	36.0	11.1	8.0	0.0	0.0	198	119	177	84
6-18-68	410	19.7	6.9	30	0.49	0.30	61.0	11.0	8.4	0.0	0.0	75	44	133	79
6-20-68	410	20.4	6.9	30	0.39	0.29	74.0	9.8	7.9	0.0	0.0	114	34		54
6-20-68	410	22.4	6.9	30	2.77	1.46	53.0	10.75	8.5	0.0	0.0	233	97	178	82

NOTES: Dissolved oxygen could not be determined due to interference by chlorine.

Overall input air average temperature was 19.9° C (67.5° F).

Average Per Cent Relative Humidity (% R.H.): Contactor input 81%, Contactor discharge 94%

H_2S REMOVAL WITH CALCIUM HYPOCHLORITE
AT 100, 200 AND 400 PPM AVAILABLE
CHLORINE RESIDUAL
15 GAL. SOLUTION IN CONTACTOR, NO RECIRCULATION
CONTACT AREA: 12250 FT^2/MINUTE

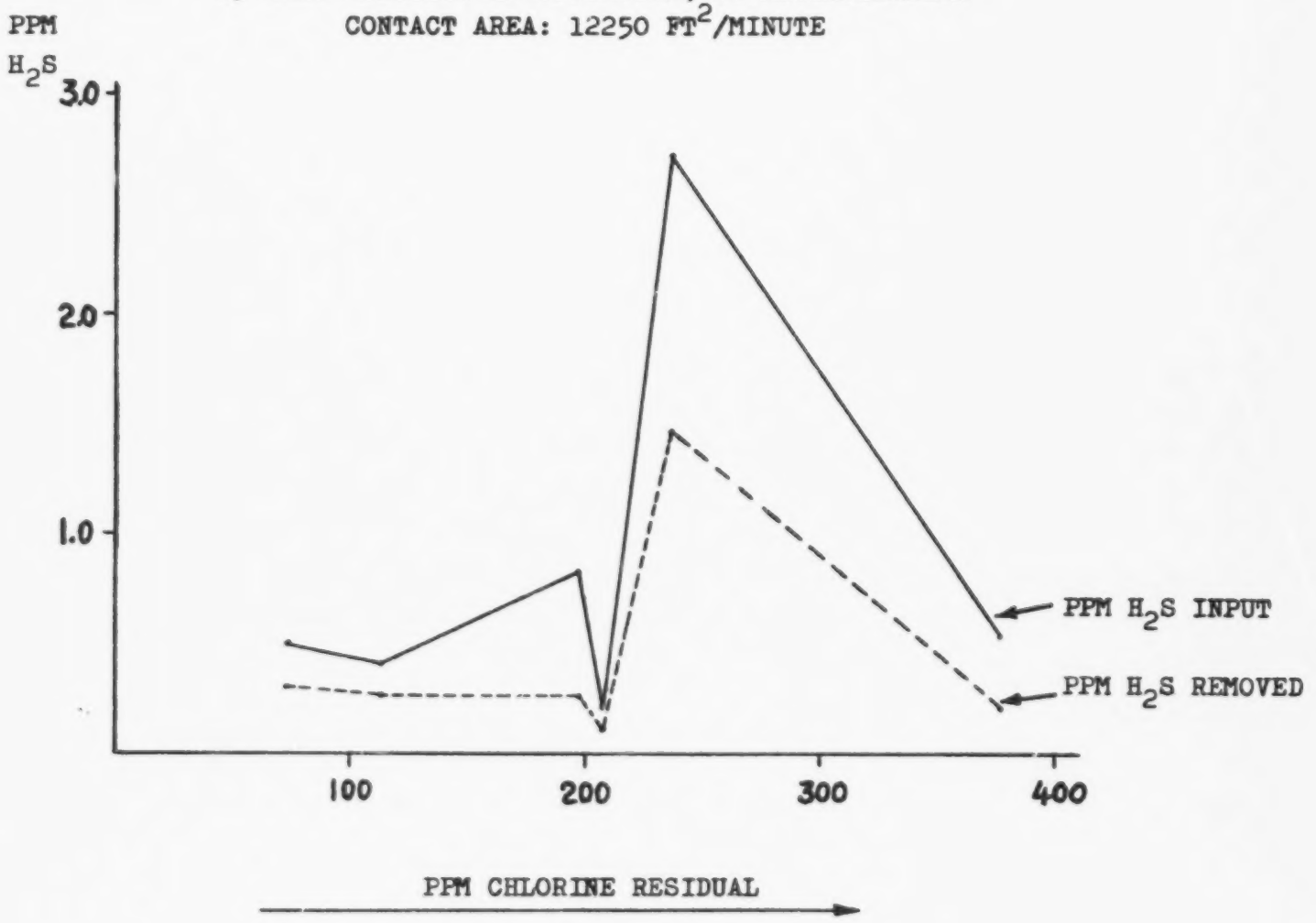


FIG. #21

TABLE #12

H_2S REMOVAL WITH CALCIUM HYPOCHLORITE AT 10,000 PPM; 15,000 PPM and 20,000 PPM AVAILABLE CHLORINE RESIDUAL 15 GAL. SOLUTION IN CONTACTOR – NO SOLUTION RECIRCULATION – 12,250 FT^2/MIN CONTACT AREA

DATE	AIR FLOW STD. CFM	°C	AIR RESIDENCE TIME SECONDS	LENGTH OF RUN MIN	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	pH START	pH END	PPM RESIDUAL CHLORINE IN THE SOLUTION PPM START	PPM RESIDUAL CHLORINE IN THE SOLUTION PPM END	PPM TOTAL ALKALINITY START	PPM TOTAL ALKALINITY END
7-1-68	407	22.5	6.9	120	8.78	5.28	60.0	12.4	8.0	7,084	2,552	6,440	3,220
7-3-68	408	20.4	6.9	180	1.54	0.94	61.0	12.3	7.8	16,370	12,140	12,320	5,240
7-10-68	403	24.6	6.9	180	3.56	2.84	80.0	12.3	7.4	20,240	13,110	15,480	4,320
7-15-68	403	24.6	6.9	120	7.00	4.51	64.0	11.7	7.9	19,228	16,104	14,880	8,420
7-24-68	400	26.3	7.0	120	7.29	5.30	73.0	11.95	8.2	19,844	17,160	15,050	9,930

NOTES: Dissolved oxygen and dissolved sulfides could not be determined due to interference by chlorine.

Overall input air average temperature was 23.7° C (72.8° F).

Average Per Cent Relative Humidity (% R.H.): Contactor input 83%, Contactor discharge 91%.

H_2S REMOVAL WITH CALCIUM HYPOCHLORITE
AT 10,000, 15,000 AND 20,000 PPM AVAILABLE Cl_2
15 GAL. SOLUTION IN CONTACTOR, NO RECIRCULATION
CONTACT AREA: 12,250 FT^2/MINUTE

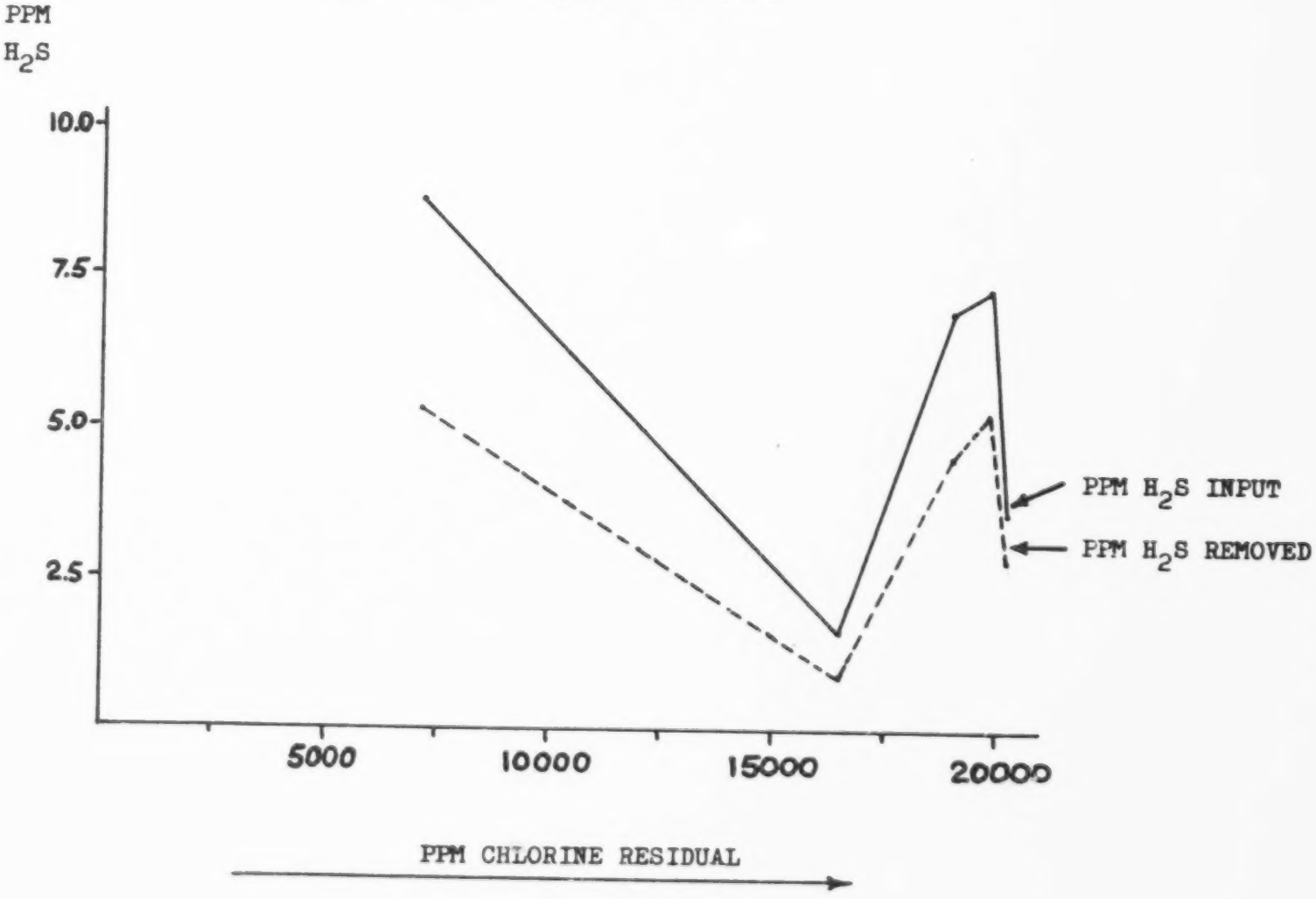


FIG. #22

POTASSIUM PERMANGANATE

A series of runs were performed with 1%, 5% and 10% Potassium Permanganate in tap water solution and at pH values of 6.0, 8.0 and 9.0. Also, two commercial proprietary compounds were tested to determine their H_2S removing capacity. One of the proprietary compounds was basically a 5% Potassium Permanganate solution. Its behavior in removing H_2S was in line with a plain solution of Potassium Permanganate of corresponding strength. Doubling the recommended concentration of this product did not show a proportional removal of H_2S., The odor of discharged air from the 2-phase contactor was offensive. The other proprietary compound was organic in nature, and commonly used to mask offensive odors in sewage. Used in concentrations of up to or in excess of 1:200,000 caused excessive foaming. H_2S removal was fairly low or erratic. The mixture of foul air plus this compound in water gave an extremely offensive odor.

See Table #13; Fig. #23 and #24.

References: See (2), (5), (17), (18) in Bibliography.

TABLE #13

H_2S REMOVAL WITH POTASSIUM PERMANGANATE AT 1%, 2%, 5% and 10% CONCENTRATION
15 GAL. SOLUTION IN CONTACTOR – NO RECIRCULATION – 12,250 FT^2/MINUTE
(OR 16 DISCS AT 53 R.P.M.)

DATE	AIR FLOW STD. CFM	INPUT FOUL AIR TEMP °C	AIR RESIDENCE TIME SEC.	LENGTH OF RUN MIN.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	pH START	pH END	% $KMnO_4$ IN THE SOLUTION START	% $KMnO_4$ IN THE SOLUTION END	REMARKS
8-22-68	400	24.3 C	6.9	120	2.83	1.27	45.0	–	–	0.996	0.86	
8-22-68	430	25.6 C	6.5	120	8.42	6.02	72.0			(2% $KMnO_4$ Solution) TITRATION IMPOSSIBLE		ISOPROPYL ALCOHOL ADDED
8-28-68	400	27.3 C	6.9	120	7.10	2.82	40.0	9.5	7.85	7.12	6.86	
9-10-68	400	24.2 C	6.9	120	10.83	6.97	64.0	8.9	7.4	2.74	2.64	
9-20-68	410	20.5 C	6.8	150	6.74	3.42	51.0	7.5	6.9	4.68	4.71	
9-24-68	400	28.0 C	6.9	240	4.65	2.09	45.0	8.55	6.40	0.98	1.11	VOLUME LOSS THRU EVAPORATION
9-25-68	400	24.2 C	6.9	300	6.08	1.64	27.0	6.68	6.25	0.75	0.75	
9-27-68	400	22.7 C	6.9	180	6.39	2.87	45.0	9.26	8.84	3.76	3.20	
10-2-68	410	21.8 C	6.8	60	9.14	2.28	25.0	8.65	7.56	0.99	0.69	STEAM INJECTED (3 MIN.)
10-4-68	410	21.9 C	6.8	40	3.48	1.73	50.0	8.54	7.92	0.98	0.83	STEAM INJECTED (10 MIN.)

NOTES: Overall input foul air temperature range was 20.0° C to 30.0° C (68.0° F to 86° F).
Average Per Cent Relative Humidity (% R.H.): 8-22-68/9-27-68 Contactor input 70%, Contactor discharge 83%
10-2-68/10-4-68 Contactor input 99%, Contactor discharge 90%

DETERMINATION OF H_2S REMOVAL WITH POTASSIUM PERMANGANATE SOLUTION

APPROX. pH= 9.0
400 C.F.M.. AIR FLOW
15 GAL. $KMnO_4$ SOLUTION - NO RECIRC.
12250 FT^2/MIN-RANGE H_2S INPUT: 2.8 - 10.8 PPM

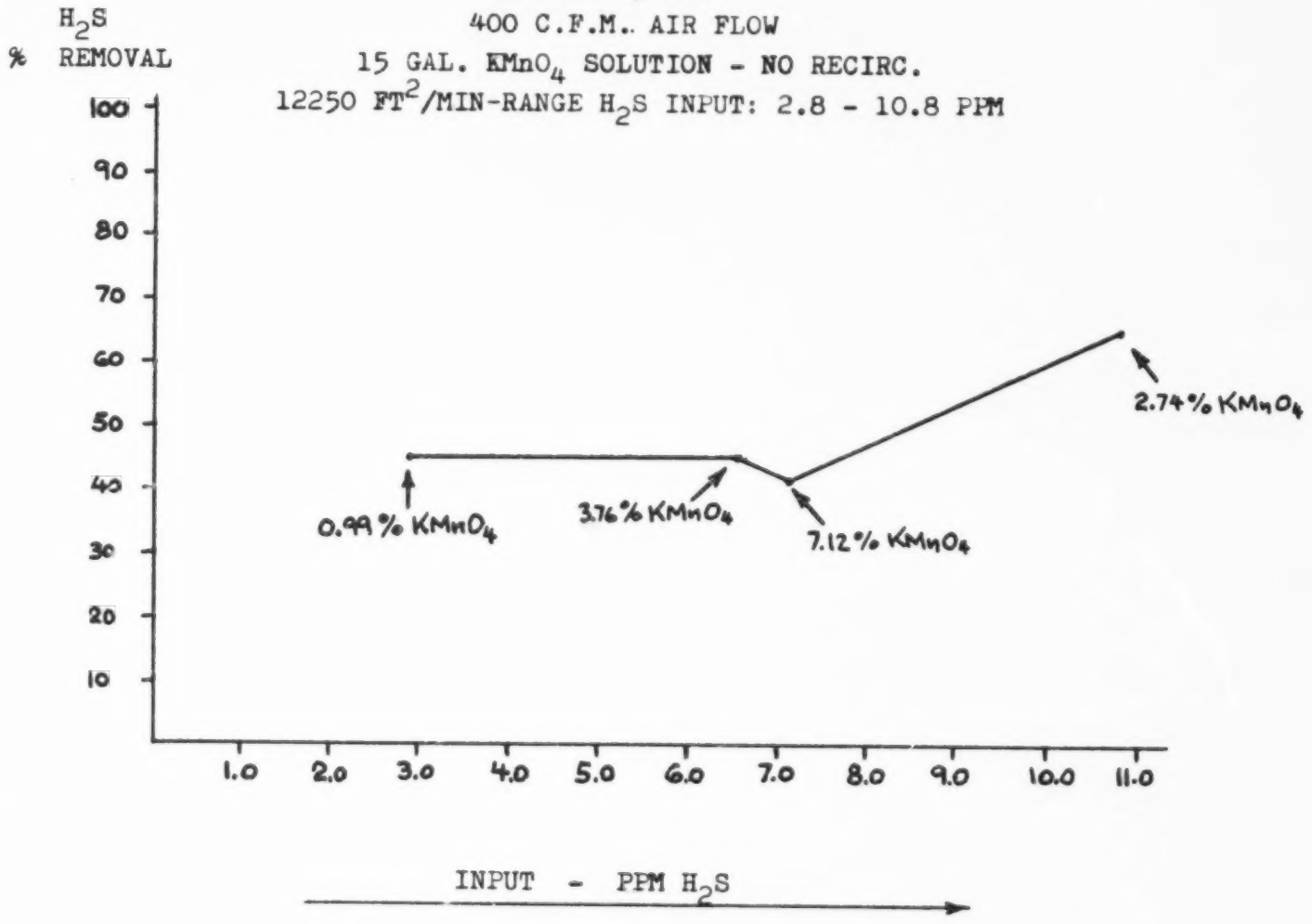


FIG. #23

DETERMINATION OF H_2S REMOVAL WITH
POTASSIUM PERMANGANATE SOLUTION
APPROX. pH= 9.0
400 C.F.M. AIR FLOW
15 GAL. $KMnO_4$ SOLUTION - NO RECIRC.
12246 FT^2/MIN.
RANGE H_2S INPUT: 2.8 to 10.8 PPM

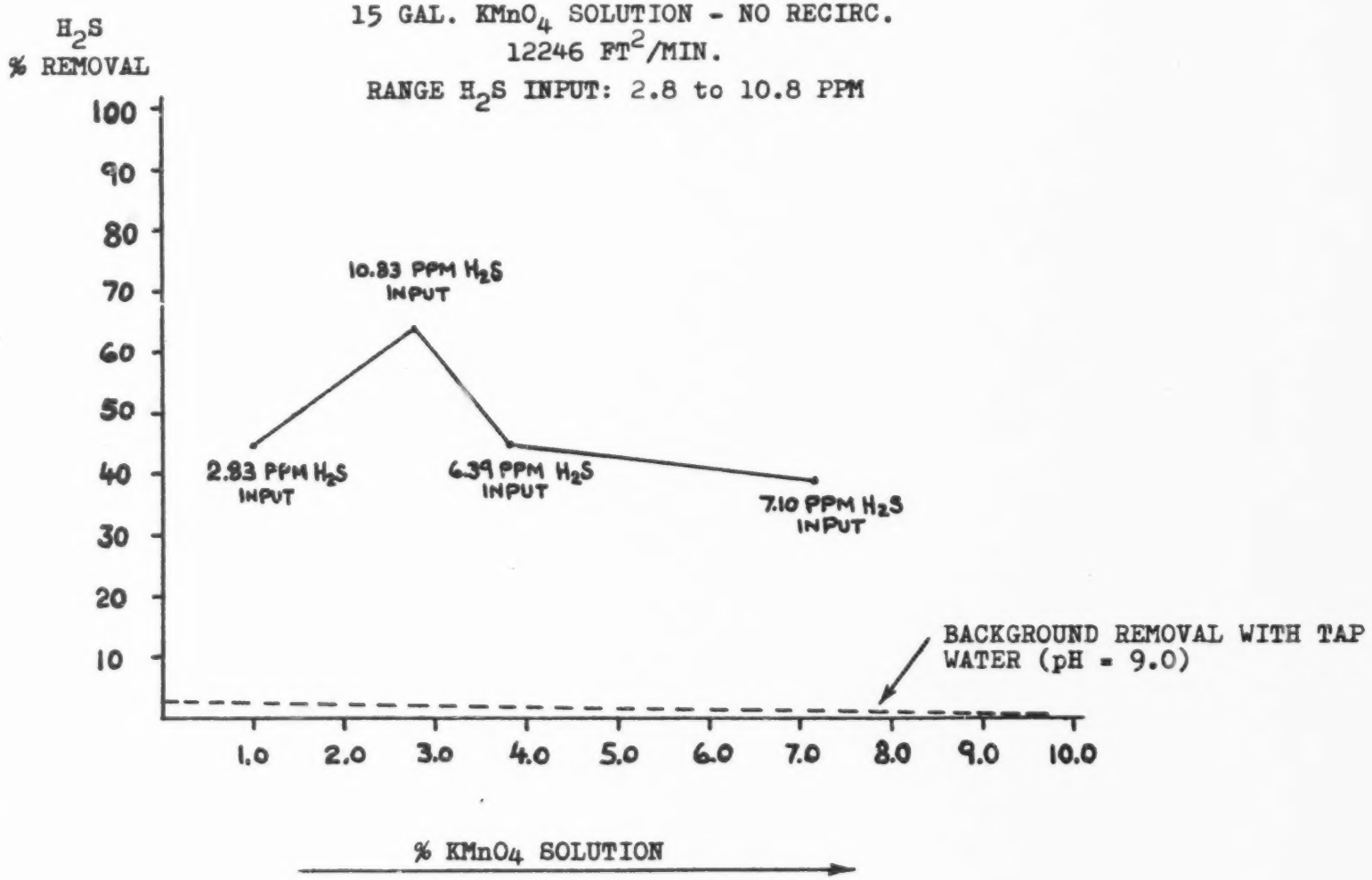


FIG. #24

ACTIVATED SLUDGE

An activated sludge was developed using raw sewage (see Table #14 for typical analyses) as a base, seeded with algae from the re-aerator of an activated sludge plant and an operating oxidation pond. Compressed air maintained continuous aeration in a 50 gal. tank holding activated sludge. The daily procedure consisted of removing by syphoning 30 gal. of fresh raw sewage into the holding tank. The reason behind the daily loading of raw sewage was to maintain activated sludge solids in the range of 3,000 PPM as suspended solids to use in removing the sulfides. Once having established an activated sludge which shows promise of sulfide removal up to 50%, the next step would be to form an increased contact area substrate by using a chelated iron-ammonium complex in the activated sludge. Supplemental feeding of sugar (sucrose) was used to increase the bacterial activity, and to slowly culture a "foul air" eating floc.

In the extraction section of the contactor about 15 gal. of recirculated activated sludge was used as the sulfide removing agent passing a foul air flow of 500 to 1,000 C.F.M. through the unit.

A typical run shows an average dissolved oxygen concentration of 5.0 to 7.0 PPM in the supernatant and will show an average of 1.2 PPM dissolved oxygen in the recirculated activated sludge with foul air flow of 500 to 1,000 C.F.M. containing 0.2 to 1.5 PPM sulfides (low winter concentration.)

The dissolved oxygen concentration in the supernatant depends on bacteria and algae population, foul air flow, surface, and temperature. Cold winter weather and night irregular air supply used in the aeration of the sludge in the holding tank slowed down activated sludge production.

Runs at 55 R.P.M. disc speed (12,700 to 15,300 Sq. Ft./min. contact area) using 500 and 1,000 C.F.M. of foul air to the contactor show about 60% sulfide removal. Input sulfide range was 0.2 to 2.2 PPM. Odor of discharged air was not unpleasant. The rainy conditions then resulted in a relative low level of sulfides in the foul air source.

See Table #15.

TABLE # 14

TYPICAL RAW SEWAGE INFLUENT ANALYSIS 1968/69
SAN DIEGO METRO SYSTEM, POINT LOMA INFLUENT

FLOW	82.5 MGD
TEMP.	68 – 83° F
pH	7.2
SUSP. SOLIDS	250 – 300 PPM
VOL. SUSP. SOLIDS	180 – 240 PPM
CONDUCTIVITY	2,800 Micromhos/cm.
B.O.D.	220 – 240 PPM
TOTAL DISSOLVED SOLIDS	2,200 PPM
TOTAL HARDNESS	395 PPM
CALCIUM	110 – 134 PPM
MAGNESIUM	46 – 48 PPM
SODIUM	340 – 460 PPM
POTASSIUM	46 – 70 PPM
AMMONIUM	19 – 20 PPM
SULFIDE	2 – 5 PPM
PHOSPHATE	30 – 40 PPM
ABS	5 – 10 PPM
BICARBONATE	300 PPM
SULFATE	362 PPM
CHLORIDE	400 – 600 PPM
FLUORIDE	1 PPM
BORON	0.88 PPM
SILICA	30 – 40 PPM

Primary treatment removal averages 60% susp. solids and 40% B.O.D.

CHELATED IRON - AMMONIUM COMPLEX

A chelated iron - ammonium complex was tried as an addition to the activated sludge used for sulfide removal. The purpose of the addition of the iron - ammonium chelate is two-fold: a) To promote the development of strains of iron-sulfur bacteria which, in turn, will fix the sulfides for oxidation; b) To increase the contact area by the suspensoid floc that is obtained with the iron - ammonium chelate.

Two concentrations of the iron - ammonium chelate were 10 PPM and 20 PPM as iron. The stronger concentration of iron - ammonium chelate does not seem to reflect proportionately better sulfide removal. Sulfide removal obtained by activated sludge and by activated sludge plus iron - ammonium chelate fell within basically the same range in both instances, i.e., about 40 - 50% H_2S removal.

Some changes made in the physical set-up were lowering the holding tank and rearranging the pumping flow so that all activated sludge is pumped from the contactor into the holding tank and from it back to the contactor by gravity. The purpose of this change is to stabilize levels in the holding tank and in the contactor to facilitate longer runs.

Activated sludge solids (3,000 PPM) were used with and without addition of iron - ammonium chelated complex at 10 PPM and 20 PPM as iron. Hydrogen sulfide and odor removal were monitored.

Input sulfide range was 0.45 - 2.5 PPM hydrogen sulfied and sulfide removal was in the 40 - 50% removal range in both instances, with and without addition of iron - ammonium chelate to the activated sludge.

Judgement upon the odor of discharge air was from slightly foul to foul.

TABLE #15

HYDROGEN SULFIDE REMOVAL WITH ACTIVATED SLUDGE

ACTIVATED SLUDGE VOLUME: 15 GAL. IN CONTACTOR AND 65 GAL. TOTAL VOLUME, UNDER RECIRCULATION

CONTACT AREA: 12,700 TO 15,300 Sq. Ft.^{2}/MIN.

DATE	AIR FLOW STD. CFM	AIR RESI-DENCE TIME SEC.	INPUT FOUL AIR TEMP. °C	OVERALL LENGTH OF RUN DAYS	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	SUSPENDED SOLIDS PPM	REMARKS
1-7-69 to 1-15-69			Establishing activated sludge						
1-16-69									
09:20	1,000	2.8	17.8	1	2.2	1.2	57.0	1,773	
09:39	1,000	2.8	18.2	1	1.5	0.9	60.0		
11:40	1,000	2.8	18.4	1	0.2	0.1	50.0		
1-17-60									
11:04	500	5.3	18.3	2	4.4	2.0	45.0	1,776	
2-12-69									
15:05	1,000	2.8	18.5	28	1.4	0.8	57.0	3,364	
3-20-69									
15:10	1,000	2.8	19.5	66	2.0	1.1	55.0	2,762	Added 20 PPM of iron chelate.
3-25-69									
11:15	1,000	2.8	22.0	71	1.9	1.0	52.0	1,874	30 min. after addition of 1 lb Celite and 20 PPM iron chelate.

NOTE: Average Per Cent Relative Humidity (% R.H.) was:
Contactor input 79%, Contactor discharge 97%.

At low sulfide levels (0.5 – 2.0 PPM H_2S), approximately 60% hydrogen sulfide removal is observed.

At higher levels (1.5 – 5.0 PPM H_2S), approximately 45 to 50% hydrogen sulfide removal is observed.

RAW SEWAGE

Results from a raw sewage run are noted - 15 gal. of raw sewage in contactor with no recirculation.

Range: 5 - 14 PPM hydrogen sulfide input. Average removal was 2.95 PPM H_2S or 33.4%.

Temperature of foul air was 20.8°C. at start of run and 16°C. at the end.

The pH varied from 7.4 at start to 8.13 at the end. Pomeroy method for total and dissolved sulfides showed 2.5 to 0.2 PPM and 2.3 to 0.0 PPM respectively, at start and end of the run.

OZONE

Ozone is a powerful oxidizing agent and should remove sulfide and other odors of sewage origin. The original plan called for construction of an ozone generation chamber through which the foul air would be ducted and conveyed to the two phase contactor. The ozone lamps were Westinghouse G37T6VH sterilamp ultraviolet tubes rated at 35 grams ozone production per hour per lamp. Three different designs of ozone chambers were tested with four ozone lamps placed inside each chamber. Performance of the ozone lamps seemed very erratic; thus, the reason for the change in design of the ozone chambers to overcome certain inherent ozone characteristics, such as self-destruction when linear flow velocity past the lamps is low.

OZONE CHAMBERS

For experimental purposes three different ozone chambers were constructed:

Ozone Chamber, Design #1 (May 1969 - July 1969):
Ozone lamps were placed horizontally and at 90° angle against air flow. Lamps separated 6" from each other.
See Fig. #25.

Ozone Chamber, Design #2 (August 1969 - October 1969):
Ozone lamps placed horizontally and in the same direction as air flow. Lamps separated 6" from each other.
See Fig. #26.

Ozone Chamber, Design #3 (November 1969 - June 1970):
Ozone lamps placed horizontally and at 90° angle against air flow. The lamps are separated from each other
sections by use of laminar flow straighteners. This specific design is to avoid ozone self destruction when flow conditions are turbulent.
See Fig. #27 and #28.

OZONE CHAMBER #2

AUGUST - SEPTEMBER 1969

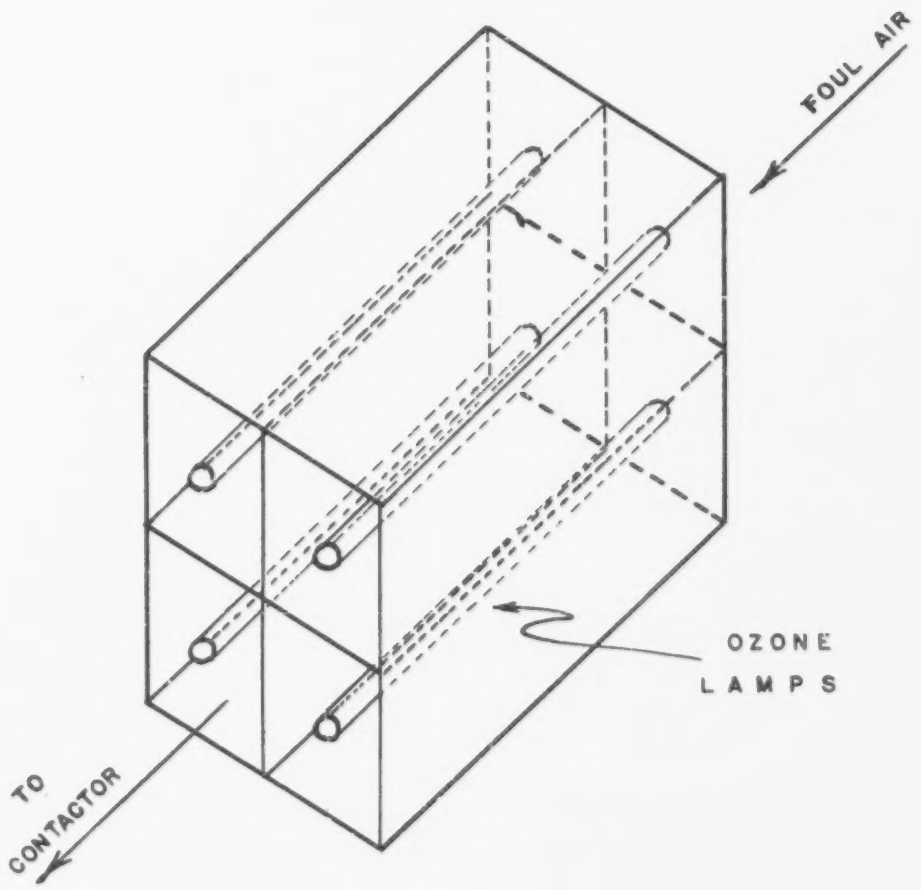


FIG. #26

OZONE CHAMBER #1

MAY 1969 - AUGUST 1969

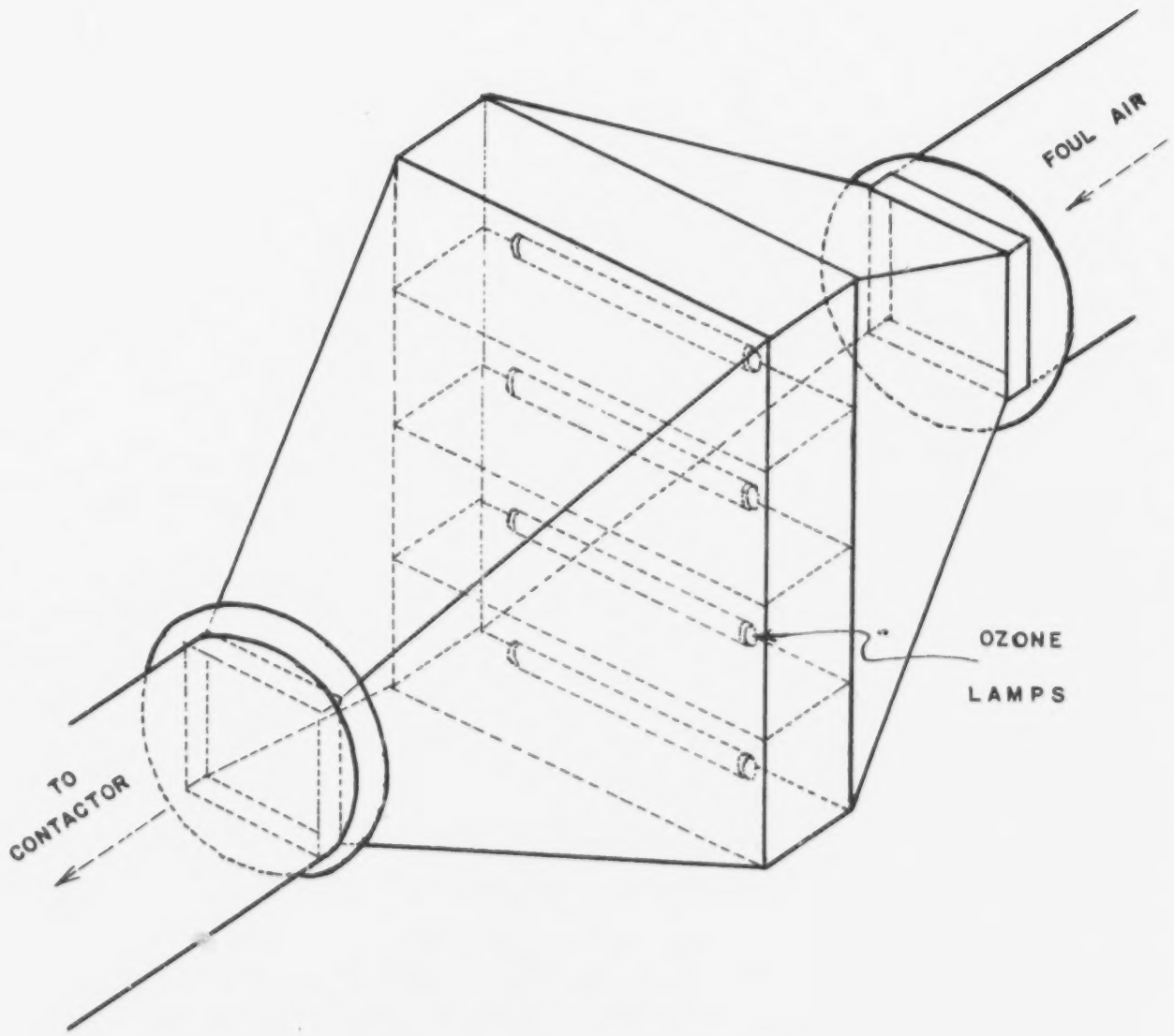


FIG. #25

OZONE CHAMBER #3

NOVEMBER 1969 - JUNE 1970

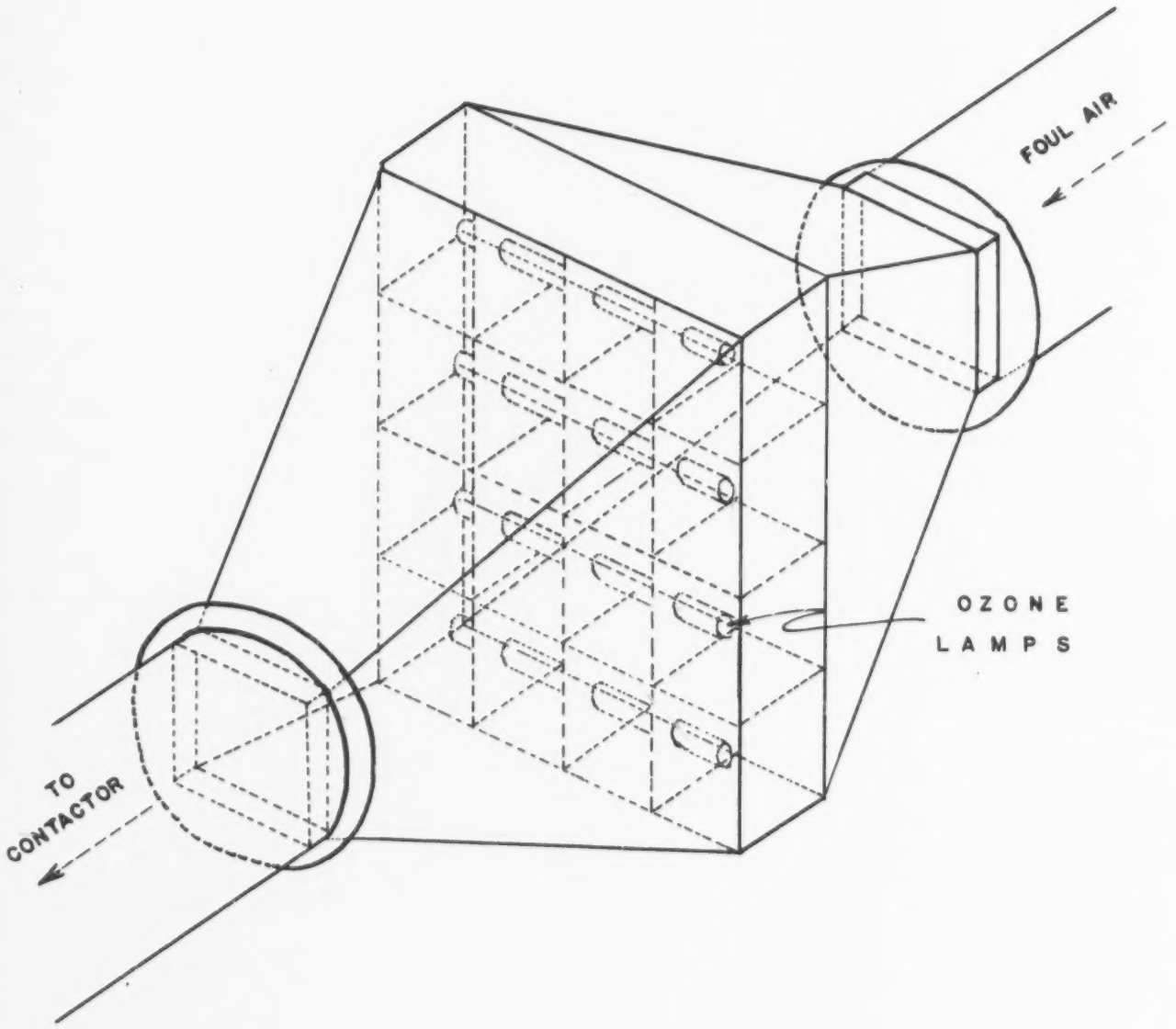


FIG. #27

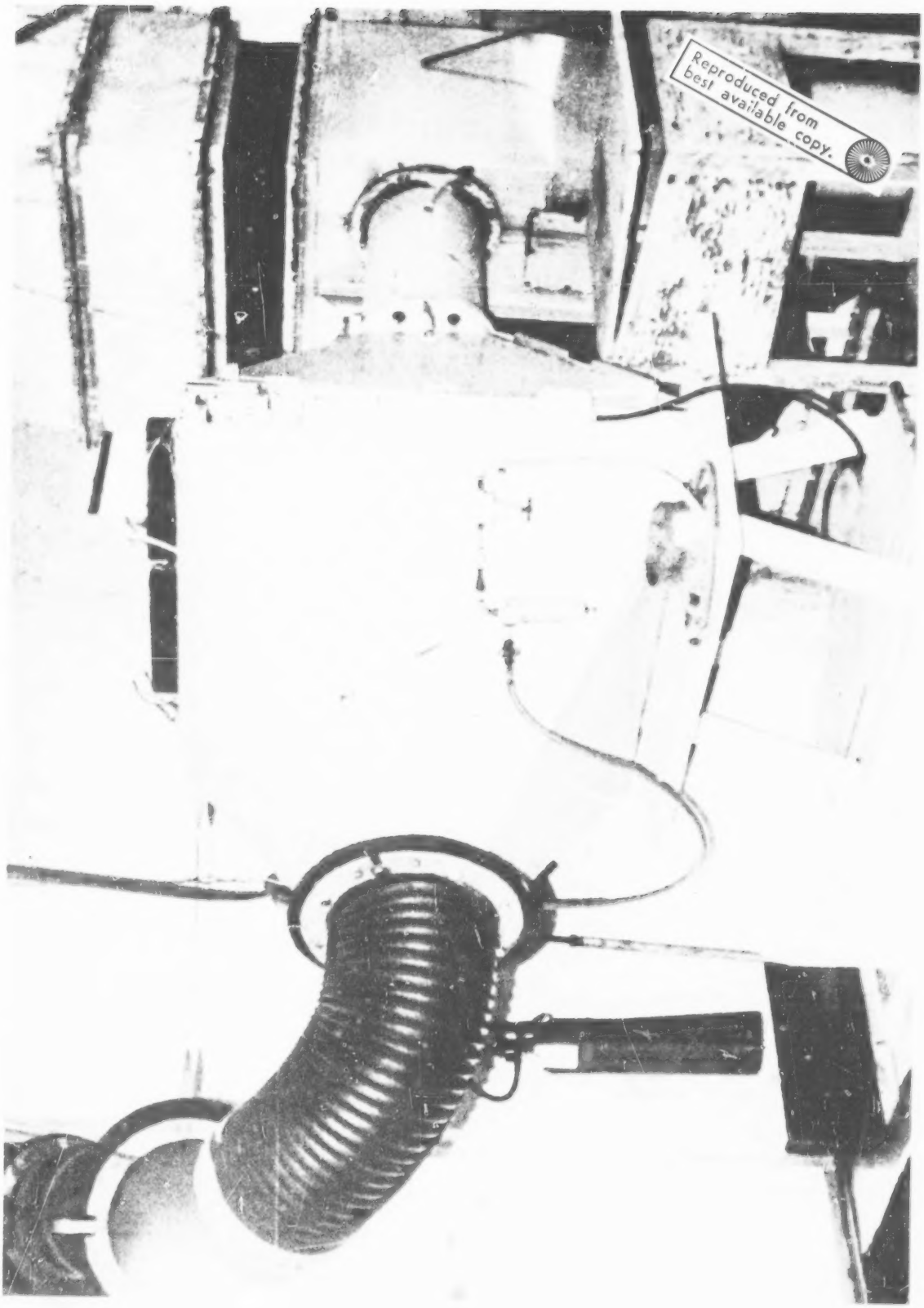


FIG. #28
VIEW OF OZONE CHAMBER #3.

EXPERIMENTAL CONDITIONS

A diversity of air flows were tested: 150 to 400 C.F.M. fresh air and 200 to 1,000 C.F.M. foul air.

Input hydrogen sulfide levels varied from 2.0 to 80.0 PPM. A total volume of 25 gal. tap water was used in the two phase contactor and tank, with continuous recirculation. The total contact area was 18,800 ft. ^{2}/min. (20 discs at 65 R.P.M.). See Fig. #29 and Table #16.

As one way to accurately sample high concentrations of H_2S, the dilution needle method was tried. Result: In practice, almost no foul air is drawn through needle and quantitative results are not reliable.

Theory of dilution needle: A small part of high H_2S concentration foul air taken through needle and diluted with fresh air drawn with A.I.S.I. compressor - this should accomplish required diluted H_2S values for A.I.S.I. readouts.

Hydrogen sulfide removal with the ozone amounts that were available was found to be erratic. Judgement of ozone treated foul air discharged to the atmosphere was carried out by sewage treatment plant personnel without existence of a formal odor panel.

Quality of the discharged air was found to be fair to good. Caution: Action of ozone upon nasal nerves should be kept in mind, since they become dulled upon exposure. Use of special safety goggles is mandatory when looking at the ozone lamps.

After several hours of operation, the solution in the two phase contactor seemed to be saturated with H_2S and at times it gave off H_2S gas.

Age of the ozone lamps seems to be critical. After about nine months of operation, ozone was not detectable, except by going to static conditions, no air flow.

PROGRESSIVE H_2S REMOVAL WITH FOUR NEW OZONE LAMPS AND
25 TO 30 GALLONS RECIRCULATED TAP WATER IN TWO PHASE CONTACTOR
FOAMING CONDITIONS: 800-1,000 C.F.M. FOUL AIR
AVERAGE RUN DURATION: 2-3 HOURS.
CONTACT AREA: 18,800 SQ. FT./MINUTE.

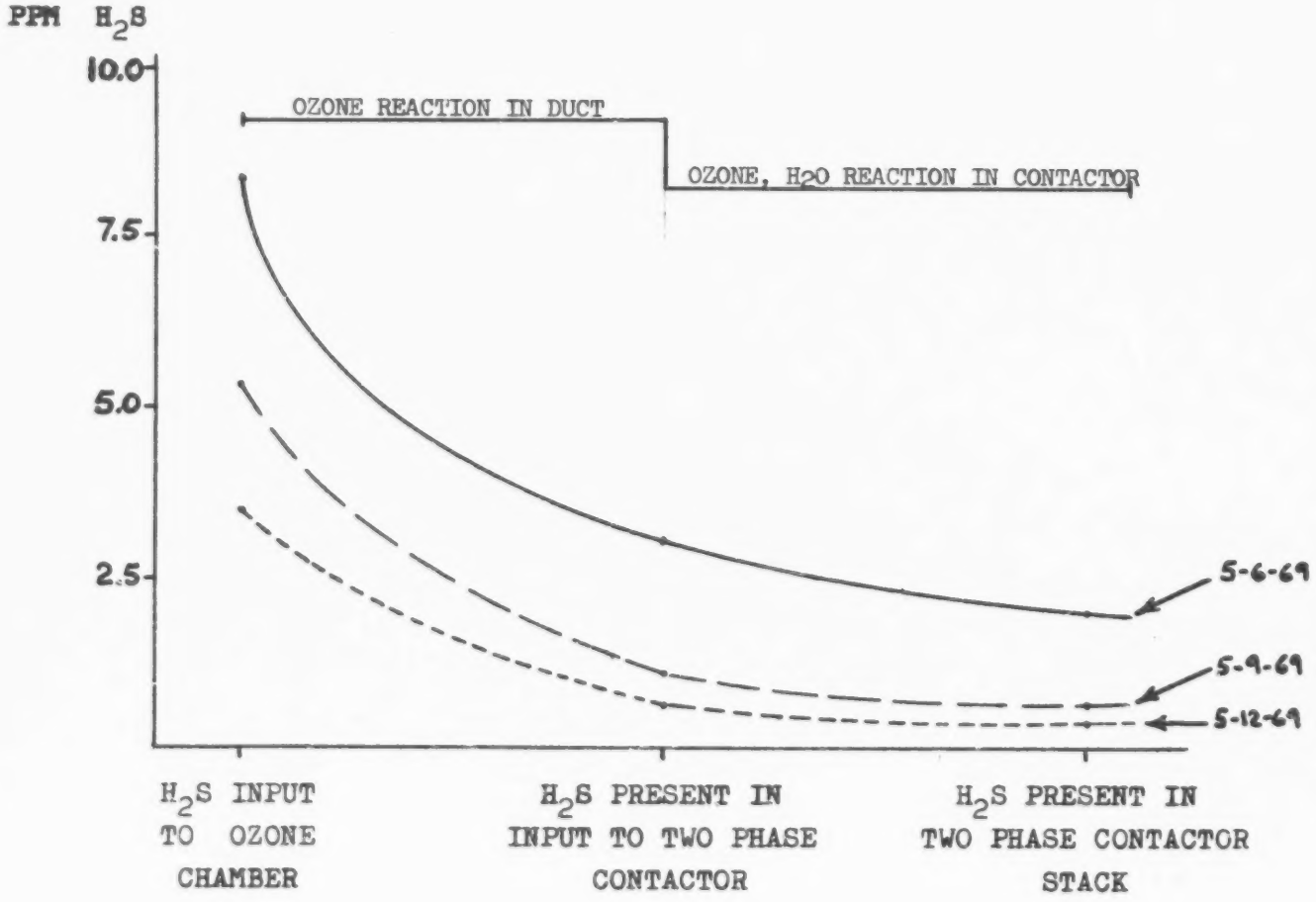


FIG. #29

TABLE #16

HYDROGEN SULFIDE REMOVAL WITH FOUR NEW OZONE LAMPS AND 25 TO 30 GALLONS RECIRCULATED TAP WATER IN TWO PHASE CONTACTOR FOAMING CONDITIONS. CONTACT AREA: 18,800 SQ. FT.^{2}/MIN.

DATE	AIR FLOW STD. CFM	AIR RESIDENCE TIME SEC.	INPUT FOUL AIR TEMP. °C	OVERALL LENGTH OF RUN MIN.	INPUT H_2S PPM	H_2S REMOVED PPM	%	NUMBER OF OZONE LAMPS ON	AGE OF LAMPS	REMARKS
5-6-69										
09:45	800	3.3	17.0	30	13.2	11.7	87.0	4	New	Light rain
10:15	800	3.3	17.6	60	7.8	4.3	50.0	4	New	
11:10	800	3.3	17.1	115	4.0	3.1	77.0	4	New	
5-9-69										
09:20	1,000	2.8	21.0	20	5.3	4.6	87.0	4	New	
5-12-69										
13:00	800	3.3	20.2	105	3.5	3.2	91.0	4	New	
14:15	800	3.3	20.3	180	4.3	3.9	90.0	4	New	

NOTES: Overall input foul air temperature was 17.0° C to 23.0° C (62.6° F to 73.6° F).

Average Per Cent Relative Humidity (% R.H.) was: Contactor input 79%, Contactor discharge 95%

Observations —

Attempts to determine ozone concentrations were inconclusive, and with time, a rapid deterioration was noted in the ozone output of the ozone lamps. New lamps were not obtainable from Westinghouse at this time. Overall results were inconclusive.

Analytical ozone analysis was dubious because: a) Actual ozone production of lamps seemed to be just a fraction of rated capacity. b) A standard diffuser was used for collection of ozone in absorbing solutions, with negative results. c) Methods of California Air Pollution Control call for the use of midget impingers. With them, positive reaction could be observed only at static conditions.

References: See (4), (11), (19), (20), (21), (22), (23), in Bibliography.

ADDENDA - OZONE LAMPS

The ozone source was four lamps made by Westinghouse Corp., number G37T6VH.

Technical data for the Westinghouse G37T6VH sterilamp Ultraviolet tube.

Mean overall length (including 2 standard lamp holders)	37"
Bulb	T6
Base	Single pin
Operating current, amperes	0.420 approx.
Operating voltage, volts	115 approx.
Approx. starting volts	450
Rated average life at 0.420 amperes	7500 hrs.
U.V. output: Total watts	15 approx.
U.V. microwatts at one meter	132 approx.
Grams per hour, ozone generated in free air	35 approx.
U.V. maintenance	To be determined
Auxiliary	40 W. instant start 1 or 2 lamp lead-lag Fluorescent Transformers

CITRIC ACID, AMMONIUM CITRATE, CITRIC ACID-COPPER SULFATE MIXTURE

H_2S removal under acid conditions (low pH) was investigated, and found to be non-existent or small. Foul air flow was 1,000 C.F.M.

CITRIC ACID

A 3% citric acid solution in tap water showed a 30% average H_2S removal, but dropping with time and reaching 0% at end of a seven hours run. Input H_2S at 1.50 PPM. pH of the solution was 2.5 - Discharged air odor was acid.

AMMONIUM CITRATE

A 3% solution was tested when fresh and when old (up to two days). The pH of the solution during the run was 4.5 - 5.5 (acid side). Dissolved oxygen test was negative. On input of 1.0 PPM H_2S, the observed average H_2S removal was 25%. Slight lemonade-like odor given by discharged air.

CITRIC ACID - COPPER SULFATE MIXTURE, INCLUDING COPPER AND AMMONIUM COMPLEX AT HIGH pH VALVES

A tap water solution of 0.25% each of citric acid and copper sulfate gave these results for H_2S removal: No removal at pH=2.5% (acid side) and pH=4.5 (acid side) and up to 90% removal at pH=8.5-7.8 (alkaline side, copper - ammonium complex present here). Input of 1.0 to 2.5 PPM H_2S.
See Table #17.

ACETIC ACID, ALONE AND BUFFERED WITH AMMONIA GAS

A 1,000 PPM acetic acid solution was prepared and its H_2S removal capacity was observed. Foul air flow was maintained at 1,000 C.F.M. H2S removal was low. Discharged air odor was foul, with some acetic acid odor. At 2.0 CFH NH_3 for some time, ammonia odor was present at contactor stack.
See Table #18.

TABLE # 17

H_2S REMOVAL WITH CITRIC ACID, AMMONIUM CITRATE, CITRIC ACID–COPPER SULFATE MIXTURE

20 GAL. SOLUTION, UNDER RECIRCULATION

1,000 CFM FOUL AIR – CONTACT AREA: 18,800 FT^2/MIN.

DATE	LENGTH OF RUN MINUTES	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	AVERAGE pH	REMARKS
4-4-69	60	2.31	0.04	19.0	5.45	3% Ammonium Citrate
4-7-69	420	3.84	0.93	24.0	5.40	3% Ammonium Citrate
4-8-69	420	2.04	0.60	29.0	5.50	3% Ammonium Citrate
4-9-69	420	1.50	0.45	30.0	2.55	3% Citric Acid
4-10-69	420	1.20	NO REMOVAL		7.40	Tap water, plus surface agents (Biz, Alcohol, Laccopen)
4-14-69	60	1.35	NO REMOVAL		2.40	0.25% Citric Acid-Copper Sulfate
4-14-69	210	1.35	NO REMOVAL		4.50	Concentrated Ammonia Added
4-15-69	420	1.20	1.08	90.0	7.80	More Concentrated Ammonia added
4-17-69	110	1.50	0.69	46.0	4.50	Citric Acid-Copper Sulfate Replenished
4-18-69	75	2.58	0.60	23.0	4.85	Citric Acid-Copper Sulfate Replenished
4-18-69	SOLUTION DISCARDED					

NOTE: Air Residence Time was 2.8 Seconds.

Overall input foul air temperature range was 17.6°C to 21.4°C (63.5°F to 70.5°F).

TABLE #18

H_2S REMOVAL WITH ACETIC ACID (1000 PPM), ALONE AND BUFFERED WITH AMMONIA GAS INJECTED TO FOUL AIR

1,000 CFM FOUL AIR – CONTACT AREA: 18,000 FT^2/MIN

DATE	AMMONIA GAS INJECTED TO FOUL AIR C.F.M.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
3-18-70	–	11.3	2.9	26.0	130	3.5	4.75	Fresh 1,000 PPM Acetic Acid Solution
3-19-70	1.0	22.9	5.4	24.0	130	3.6	3.8	
3-19-70	1.0	14.2	2.5	18.0	170	3.8	5.0	Replenished Acetic Acid
3-19-70	1.0	10.9	2.5	23.0	45	5.8	4.7	Made up Solution Volume and Replenished Acetic Acid
3-19-70	2.0	10.4	2.8	27.0	55	5.2	6.4	Same Solution
3-20-70	–	16.7	5.1	31.0	180	3.6	3.7	Replenished Acetic Acid
3-20-70	2.0	7.0	4.8	35.0	75	4.9	8.9	

TOTAL WATER VOLUME: 40 gal., 25–30 gal. in contactor.

AIR RESIDENCE TIME: 2.7 Seconds.

Overall input foul air temperature range was 19.8° C to 23.5° C (67.6° F to 74.4° F).

Average Per Cent Relative Humidity: Contactor input 53%. Contactor discharge 95%.

TABLE #19

H_2S REMOVAL WITH 1% COBALT SULFATE

20–25 GAL. SOLUTION IN CONTACTOR

1,000 CFM FOUL AIR – 2.8 SECONDS AIR RESIDENCE TIME

DATE	INPUT H_2S PPM	H_2S REMOVED PPM	%	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
3-6-70	7.6	2.3	31.0	370	7.4	7.15	Fresh 1% Cobalt Sulfate, with no pH adjustment. - Recirculation
3-9-70	12.5	3.8	30.0	300	6.45	7.90	3-Day old solution, after addition of 1% Sodium Sulfite Balls. No Recirculation (Foam).
3-11-70	13.7	3.3	24.0	360	7.35	7.60	Fresh 1% Cobalt Sulfate and 1% Sodium Sulfite Balls. No pH Adjustment - No Recirculation (foam).
3-12-70	13.6	3.3	24.0	300	7.75	7.65	1-Day old 1% Cobalt Sulfate and 1% Sodium Sulfite Balls. No Recirculation (foam). Water Volume Replenished.

By retracing runs with ozone output from 4 lamps, it was found that odor of treated discharged air improves, being judged fair. H_2S removal was found to be erratic.

NOTE: 30 Gal. total solution volume. Contact area – 18,800 ft^2/min.

Overall input - Foul air temperature range was 17.6° C to 20.8° C (63.6° F to 69.5° F)

Average Per Cent Relative Humidity: Contactor input 79%, Contactor discharge 94%

COBALT SULFATE SOLUTION IN TAP WATER

A 1% cobalt sulfate solution in tap water was prepared and investigated for H_2S removal. Foul air flow was maintained at 1,000 C.F.M.

H_2S removal was disappointing, since it is known that cobalt has catalytic properties in some reactions. Discharged air odor was foul without ozone treatment and fair when the ozone lamps were turned on.
See Table #19.

AMMONIUM HYDROXIDE AND AMMONIUM ACETATE SOLUTIONS IN TAP WATER, COPPER SULFATE ADDED LATER.

A 0.05 molar ammonium hydroxide solution was investigated while foul air flow to contactor was maintained at 1,000 C.F.M. H_2S removal was good at high pH (fresh solution). Later, caustic soda was used to maintain pH, but H_2S removal was lower. Dis. air odor: strong ammonia and foul to slightly foul when using ozone, if ammonia odor was slight.

A 0.05 molar ammonium acetate solution was tried for H_2S removal. These low pH values show poor H_2S removal.

Discharge air odor: acetic acid, slightly foul. By treatment with ozone, odor of discharged air improved to some extent.
See Table #20.

Conclusions:

Removal of hydrogen sulfide was found to be in the 75-85% range on inputs of 4.5 - 32.6 PPM H_2S and when the pH was high (9.3 - 11.9), whereas a low level of removal (35 - 60% removal on input of 1.0 - 17.5 PPM H_2S) was observed when the pH was low (adjusted, when necessary with sulfuric acid) - pH 1.9 - 4.0.

The copper ion in acid solution (pH 1.9 - 4.0) was relatively ineffective in removal of hydrogen sulfide.

TABLE #20

H_2S REMOVAL WITH 0.05M AMMONIUM HYDROXIDE, 0.05M AMMONIUM ACETATE AND 0.05M COPPER SULFATE. 20–25 GAL. RECIRCULATED SOLUTION IN CONTACTOR. 1,000 C.F.M. FOUL AIR. 2.8 SECONDS AIR RESIDENCE TIME.

DATE	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN	pH START	pH END	REMARKS
2-20-70	32.6	27.2	83.0	35	10.45	9.35	0.05 M Ammonia.
2-20-70	4.5	3.4	75.0	250	10.15	11.95	Caustic soda used to maintain pH.
2-24-70	19.0	2.5	13.0	210	3.95	4.05	0.05 M Ammonium acetate, adjusted to pH 4.0 with acetic acid.
2-24-70	13.5	7.0	52.0	70	3.6	3.55	1,440 g. Copper Sulfate added.
2-25-70	12.6	6.1	48.0	465	3.6	2.2	1-day old 0.05M Ammonium Acetate. (Due to evaporation losses.)
2-26-70	17.5	6.06	35.0	240	4.0	1.75	1440 g. Copper Sulfate, adjusted to pH 4.0 with sulfuric acid.
3-2-70	1.0	0.48	47.0	15	1.9	1.9	3-day old Copper Sulfate, after replenishment to original strength.
3-4-70	6.7	4.0	60.0	420	4.0	1.95	1440 g. Copper Sulfate, adjusted to pH 4.0 with sulfuric acid.

By retracing runs with ozone output from 4 lamps, it was found that odor of treated discharged air improves, being judged fair to good, in absence of interfering ammonia odor.

However, no increase in H_2S removal was observed.

NOTES: 30 gal. total solution volume. Contact area – 18,800 FT^2/Min.

Overall input foul air temperature range was 17.3° C to 24° C (63.1° F to 75.2° F).

Average Per Cent Relative Humidity: Contactor input 67%, Contactor discharge 91%.

COPPER CHELATE SOLUTION IN TAP WATER

H_2S removal with 0.05 Molar copper chelate solution was investigated.

The solution was made up as follows:

1440 g. $CuSO_4$ $5H_2O$
2150 g. Tetra Sodium Versenate (Tech. Grade)
340 ml. Ammonium Hydroxide dissolved in
30 gal. tap water

1,000 C.F.M. foul air were treated (residence time=2.8 sec.) 20 - 25 gal. solution in contactor, recirculation - 20 discs at 65 R.P.M. or 18,800 Ft^2/min. contact area. H_2S input range was within 5 - 15 PPM H_2S. When solution was fresh (first day) H_2S removal was 71%, decreasing with age of solution, or increasing with addition of copper sulfate. See Table #21 and Fig. #30. Observations were repeated while using ozone output of 4 lamps. It was found that hydrogen sulfide removal was not improved by activating the ozone lamps. However, the overall odor was improved, being judged fair to good, except when ammonia fumes were noted immediately after ammonium hydroxide addition.

COPPER SULFATE AND AMMONIA GAS INJECTION INTO FOUL AIR

A 0.04 molar copper sulfate solution prepared in tap water was used to investigate H_2S removal under increasing pH values, starting at the original pH-4.9 of the solution. Ammonia gas was injected into the foul air stream, at a location several feet ahead of contactor. The ammonia was expected to form a copper-ammonia complex with the copper sulfate and to react with the hydrogen sulfide directly. Foul air flow was maintained at 1,000 C.F.M., and the total volume of the solution being 40 gal. with 30 gal. in the contactor.

Odor of discharged air was foul without using ozone. When ozone was in use, the foul odor decreased.

TABLE #21

H_2S REMOVAL WITH 5% OF IM COPPER CHELATE SOLUTION
20–25 GAL. SOLUTION IN CONTACTOR, UNDER RECIRCULATION
1,000 CFM FOUL AIR 2.8 SECONDS AIR RESIDENCE TIME
CONTACT AREA = 18,800 FT^2/MIN.

DATE	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
2-13-70	13.0	9.2	71.0	240	9.0	7.8	Fresh Solution
2-16-70	18.4	8.3	45.0	120	8.2	7.3	3-day old Solution
2-16-70	11.9	9.6	81.0	165	8.15	8.40	50 ml Conc. Ammonia added at 5 min. intervals
2-17-70	14.0	8.5	61.0	70	5.15	3.65	288 g. copper sulfate added at 10 min. intervals
2-17-70	10.3	4.1	40.0	40	2.65	4.45	430 g. versene added at 10 min. intervals
2-18-70	14.5	12.2	84.0	165	8.4	9.45	Periodic additions of conc. ammonia to stay at pH 8.0 to 9.0
2-18-70	15.9	11.3	71.0	75	8.35	8.55	Periodic additions of caustic soda to hold pH
2-19-70	21.2	14.4	68.0	405	8.4	11.6	6-day old solution-periodic additions of caustic soda to hold pH at 9.0 to 11.0
2-19-70	12.6	10.7	85.0	END OF RUN CONC. AMMONIA ADDED		10.85	At end of run, conc. ammonia added (pH=10.85) H_2S removal increased to 85%, on input of 12.6 PPM H_2S.

BY RETRACING RUNS WITH OZONE OUTPUT FROM 4 LAMPS, IT WAS FOUND THAT ODOR OF TREATED DISCHARGED AIR IMPROVES, BEING JUDGED FAIR TO GOOD, IN ABSENCE OF INTERFERING AMMONIA ODOR.

HOWEVER, NO INCREASE IN H_2S REMOVAL WAS OBSERVED.

NOTES: 30 GAL. TOTAL SOLUTION VOLUME.
CONTACT AREA – 18,800 FT^2/MIN.

Overall input foul air temperature range was 18.5° C to 23.6° C (65.4° F to 74.5° F).

Average Per Cent Relative Humidity (% R.H.): Contactor input 68%, Contactor discharge 89%

H_2S REMOVAL WITH 0.05 M AMMONIATED COPPER CHELATE

30 GAL. RECIRCULATED SOLUTION IN THE SYSTEM.

1000 C.F.M. FOUL AIR

CONTACT AREA: 18,800 FT^2/MIN.

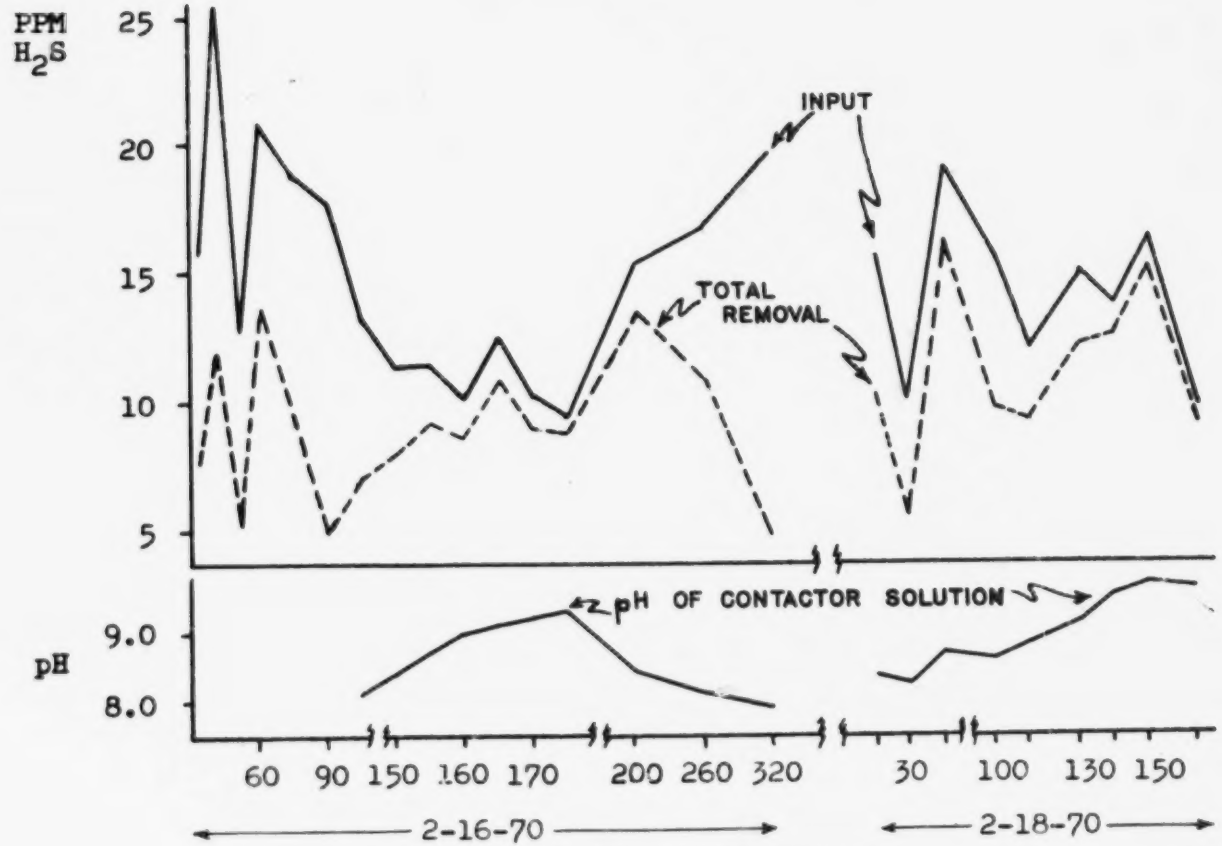


FIG. #30

TABLE #22

H_2S REMOVAL WITH 0.04 M COPPER SULFATE TAP WATER SOLUTION AND AMMONIA GAS INJECTION INTO FOUL AIR
1,000 CFM FOUL AIR – 40 GAL. RECIRCULATED SOLUTION

DATE	FOUL AIR FLOW CFM	AIR RESI-DENCE TIME SECONDS	AMMONIA GAS INJECTED TO FOUL AIR C.F.H.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
3-23-70	900	3.0	1.0	16.9	12.1	71.0	180	4.9	4.8	No ozone. Volume made up.
3-24-70	900	3.0	1.0	18.3	10.6	58.0	270	3.7	6.2	No ozone. Re-using 1-Day old solution. Volume made up.
3-25-70	800	3.3	1.0	14.8	9.3	63.0	450	7.6	8.0	Ozone on. Re-using 2-day old solution. Volume made up.
3-26-70	1,000	2.7	1.0	18.0	8.5	47.0	210	8.0	8.05	Ozone on. Re-using 3-day old solution.
3-26-70	1,000	2.7	2.0	12.6	9.1	72.0	180	8.05	8.38	Increased ammonia feed. Volume made up.
3-27-70	1,000	2.7	2.0	13.4	6.7	67.0	150	8.30	8.40	Ozone on. Re-using 4-day old solution.
3-27-70	1,000	2.7	3.0	9.9	7.3	74.0	120	8.50	8.55	Increased ammonia feed. Volume made up.

NOTES: Contact area: 18,800 FT^2/Min.

Solution volume in contactor = 30 gal. (Total vol. = 40 gal.)

Copper ion concentration:

At start (3-23-70) = 2,220 PPM Cu ++
After 10 hrs. of operation (3-25-70 10:15 a.m.) = 0.0 PPM Cu ++

H_2S removal before and after depletion of copper ion were similar.

Overall input foul air temperature range was 18.0° C to 24.0° C (64.3° F to 75.2° F).
Average Per Cent Relative Humidity: Contactor input 74%, Contactor discharge 94%

H_2S REMOVAL WITH 0.04M COPPER SULFATE PLUS 1.0 C.F.H. FEED RATE AMMONIA GAS INJECTED INTO 1000 C.F.M. FOUL AIR

40 GAL. SOLUTION IN THE SYSTEM, RECIRCULATED.
CONTACT AREA: 18,800 FT^2/MIN.

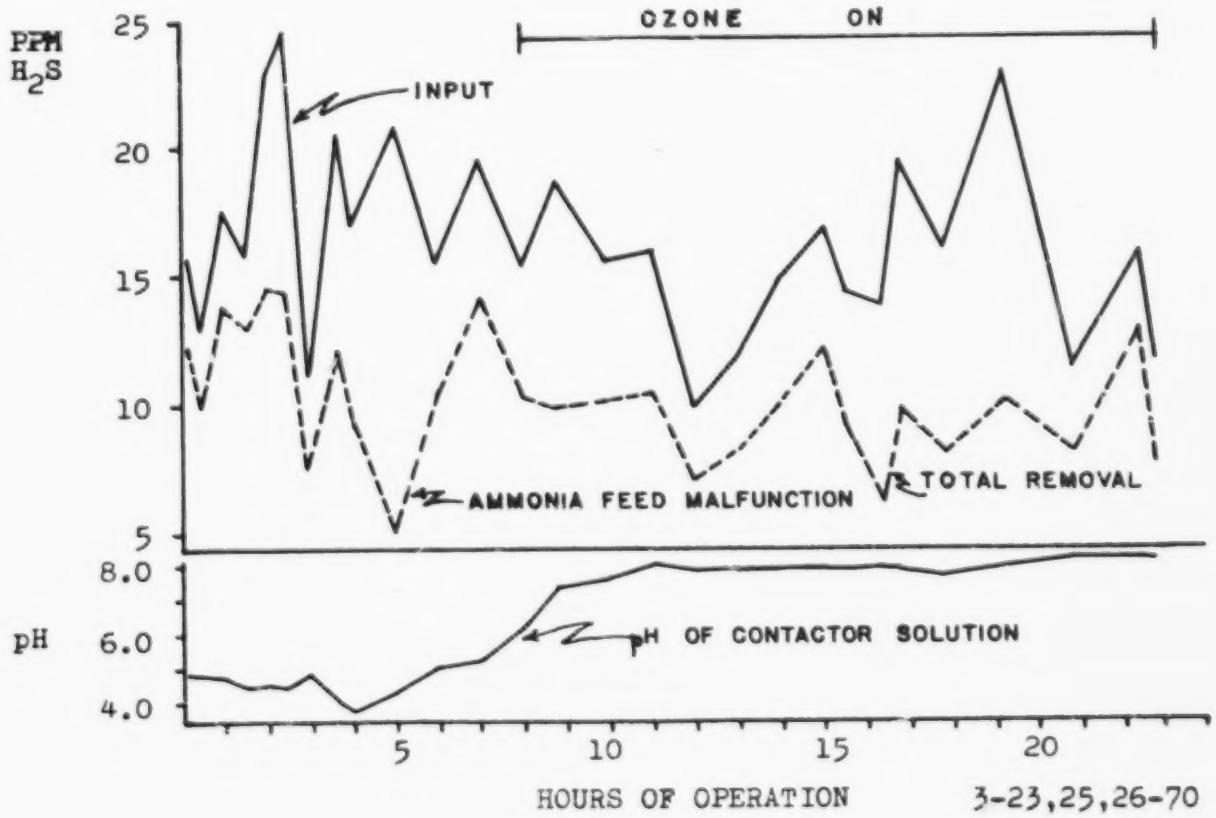


FIG. #31

TABLE #23

H_2S REMOVAL WITH 0.04 M. COPPER SULFATE IN TAP WATER SOLUTION – CHLORINE GAS INJECTED INTO FOUL AIR AT A POINT 20 FEET AHEAD OF CONTACTOR

DATE	FOUL AIR FLOW C.F.M.	AIR RESIDENCE TIME SECONDS	CHLORINE GAS INJECTED INTO FOUL AIR C.F.H.	INPUT H_2S PPM	TOTAL H_2S REMOVED PPM	%	LENGTH OF RUN MIN	pH START	pH END	REMARKS
4-7-70	1,100	2.4	1.0	13.4	12.1	90.0	15	4.6	2.65	Volume made up.
	1,100	2.4	2.0	17.8	14.0	79.0	10	2.65	2.1	
	1,100	2.4	3.0	15.1	12.4	82.0	10	2.1	1.95	
	800	3.3	3.0	12.1	12.0	99.5	15	1.95	1.65	
	800	3.3	4.0	9.8	9.8	100.0	15	1.65	1.50	
	800	3.3	3.3	14.4	13.2	92.0	15	1.50	1.45	
	700	3.8	3.0	15.1	14.5	96.0	15	1.45	1.35	
	700	3.8	2.0	12.6	7.7	61.0	15	1.35	1.25	
	500	5.3	2.0	12.6	11.0	87.0	20	1.25	1.20	
	500	5.3	2.0	11.0	11.0	100.0	15	1.20	1.20	
	700	3.8	2.0	11.4	11.4	100.0	15	1.20	1.20	
	800	3.3	2.0	11.8	10.5	89.0	15	1.20	1.15	
	800	3.3	2.0	7.0	6.2	89.0	90	1.15	0.95	With ozone treatment
	700	3.8	2.0	9.8	9.3	95.0	25	0.95	0.9	With ozone treatment
	700	3.8	2.0	6.0	6.0	100.0	30	0.9	0.8	Without ozone treatment
	700	3.8	1.0	6.0	4.3	72.0	15	0.8	0.8	Without ozone treatment

NOTES: Total solution volume – 40 gal. (30 gal. in contactor). Solution recirculated.
Contact area – 18,800 FT^2/Min. (20 discs at 65 RPM).
Small copper depletion after 7 hrs. operation: 2,370 PPM to 2,340 PPM, since hydrochloric acid was bringing copper in copper sulfide back into solution.

Most of H_2S removal takes place in duct ahead of contactor, after chlorination point.

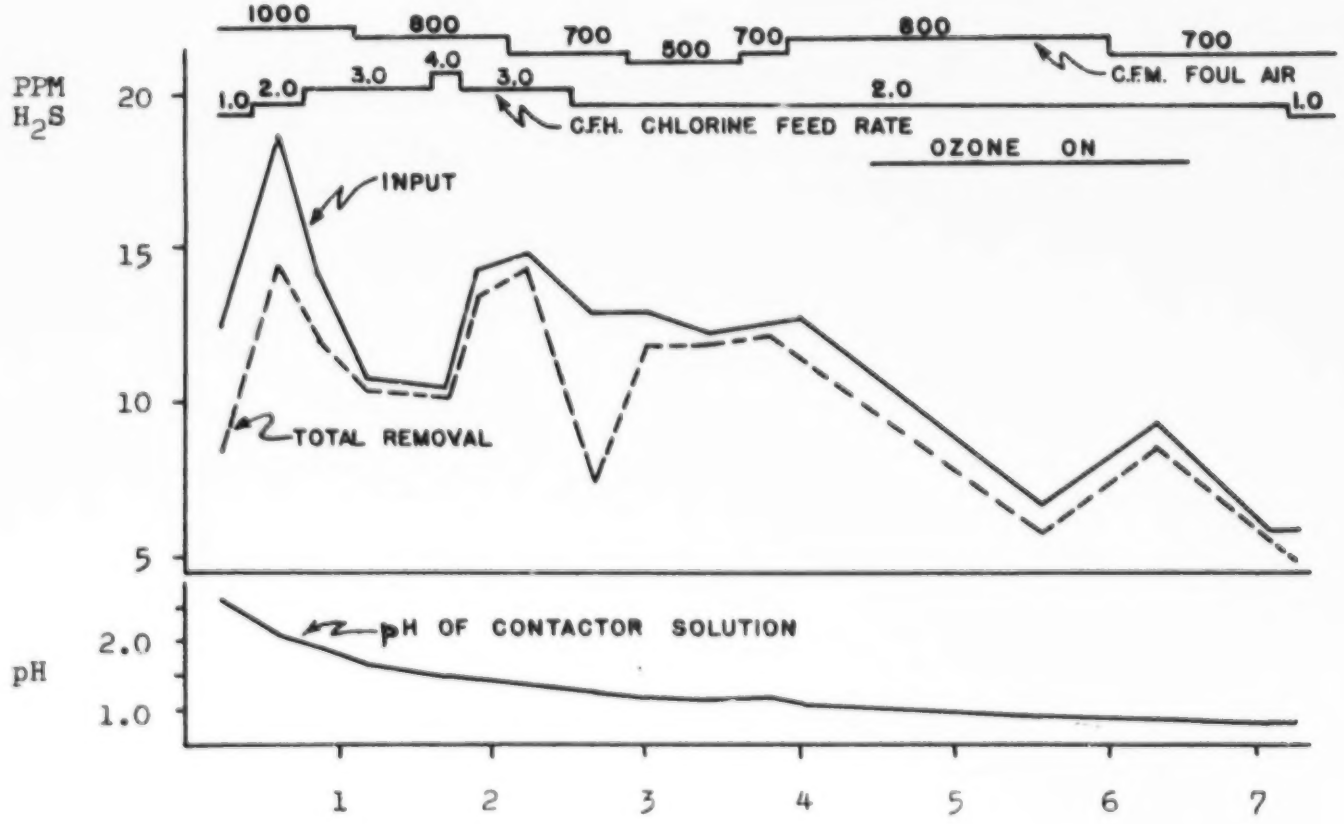
Chlorine-like odor present in discharged air.

Improvement questionable when treating in addition with ozone.

Overall input foul air temperature range was 21.6° C to 24.2° C (70.8° F – 75.5° F).

Average Per Cent Relative Humidity (% R.H.): Contactor input 65%, Contactor discharge 98%

H_2S REMOVAL WITH 0.04 COPPER SULFATE AND CHLORINE GAS
40 GAL. RECIRCULATED SOLUTION IN THE SYSTEM
CONTACT AREA: 18,800 FT^2/MIN.



HOURS OF OPERATION

4-7-70

FIG. #32

At 2.0 and 3.0 CFH ammonia feeding rate, ammonia odor was monitored at contactor stack. H_2S removal observed then was 70% approximately on an input of around 10 PPM H_2S.
See Table #22 and Fig. #31.

COPPER SULFATE AND CHLORINE GAS INJECTION AHEAD OF CONTACTOR

A 0.04 molar copper sulfate solution was prepared, loaded into contactor and recirculated. Chlorine gas was injected into foul air at a point located 6 feet ahead of contactor and later changed to a point approximately 20 ft. ahead of contactor. Foul air flow was varied from 700 to 1,100 C.F.M. Most of the H_2S removal took place in the duct ahead of contactor, and the presence of copper sulfate did not seem to enhance the removal of H_2S traces left by chlorine action. Treated discharged air had chlorine-like odor, and ozone treatment did not seem to improve it.
See Table #23 and Fig. #32.

COPPER SULFATE, CHLORINE & AMMONIA GAS

A 0.04 molar copper sulfate solution was investigated for H_2S removal when used in conjunction with chlorine gas and ammonia gas. Foul air flow was kept at 700 C.F.M. 100% H_2S removal was monitored at a chlorine feed rate of 2.7 C.F.H. Most of the H_2S removal took place in duct ahead of contactor. The copper sulfate removed H_2S when a substantial amount of the latter was left by chlorine action and the pH of the solution was high (alkaline side).
See Table #24 and Fig. #33

Ammonia action upon chlorine-treated foul air leaves a chlorine-like odor in most cases, with plenty of white fumes of ammonium chloride visible at the contactor stack discharge. Ozone action does not seem to improve that odor.

TABLE #24

H_2S REMOVAL WITH 0.04 M COPPER SULFATE IN TAP WATER SOLUTION – CHLORINE GAS AND AMMONIA GAS INJECTED INTO FOUL AIR AT A POINT 20 FEET AHEAD OF CONTACTOR

DATE	FOUL AIR FLOW CFM	AIR RESIDENCE TIME SECONDS	CHLORINE GAS INJECTED TO FOUR AIR CFH	AMMONIA GAS INJECTED TO CHLORINE TREATED AIR CFH	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN	pH START	pH END	REMARKS
4-8-70	700	3.8	2.0	0.0	11.0	11.0	100.0	30	4.35	2.1	Fresh solution. Volume made up.
4-8-70	700	3.8	2.0	0.0	4.7	4.4	94.0	150	2.1	1.3	
4-9-70	700	3.8	2.0	0.0	4.7	4.7	100.0	15	1.3	1.05	1-day old solution volume made up.
4-9-70	700	3.8	2.0	0.0	4.8	4.0	82.0	15	1.05	1.05	Plus ozone.
4-9-70	700	3.8	1.0	0.0	4.7	3.8	81.0	15	1.05	1.05	
4-9-70	700	3.8	1.0	0.0	4.7	3.8	81.0	15	1.05	1.0	Plus ozone.
	700	3.8	2.7	0.0	6.0	6.0	100.0	15	1.0	1.0	
	700	3.8	2.7	1.0	6.0	6.0	100.0	15	1.0	0.95	Excessive NH_4Cl fumes at stack. Discharged air has chlorine like odor.
	700	3.8	0.0	0.0	6.7	3.0	45.0	60	0.95	0.90	Removal by copper sulfate alone.
4-9-70	700	3.8	0.5	0.5	4.7	4.4	95.0	45	0.90	12.0	pH raised with caustic soda to keep HCl down, hence NH_4Cl at stack. NH_4Cl still visible afterwards.
	700	3.8	0.5	0.5	9.7	8.3	86.0	60	12.0	7.15	

NOTES: Total solution volume = 40 gal. (30 gal. in contactor).
Solution recirculated.
Contact area = 18,800 FT^2/MIN (20 discs at 65 RPM).
Chlorine injection: At 20 feet ahead of contactor.
Ammonia injection: At contactor input.
Copper depletion negligible at low pH values (Range 2220 ppm), and substantial at high pH values 7.5 to 12.0
2050 PPM copper depleted in 2 hrs. at the latter pH range.

Most of H_2S removal takes place in duct ahead of contactor.
However, at 0.5 C.F.H. chlorine feed rate and 10 ppm H_2S input, chlorine contributes 39% and copper sulfate 61% of total sulfide removal, at high pH values.
Chlorine – like odor in most cases.

Overall input foul air temperature range was 19.2° C to 22.2° C (66.4° F to 72.0° F).
Average Per Cent Relative Humidity (% R.H.): Contactor input 81%, contactor discharge 91%

H_2S REMOVAL WITH 0.04 M COPPER SULFATE AND CHLORINE GAS.
REMOVAL OF EXCESS CHLORINE WITH AMMONIA GAS.
40 GAL. RECIRCULATED 1-DAY OLD SOLUTION IN THE SYSTEM
700 C.F.M. FOUL AIR - CONTACT AREA: 18,800 FT^2/MIN.

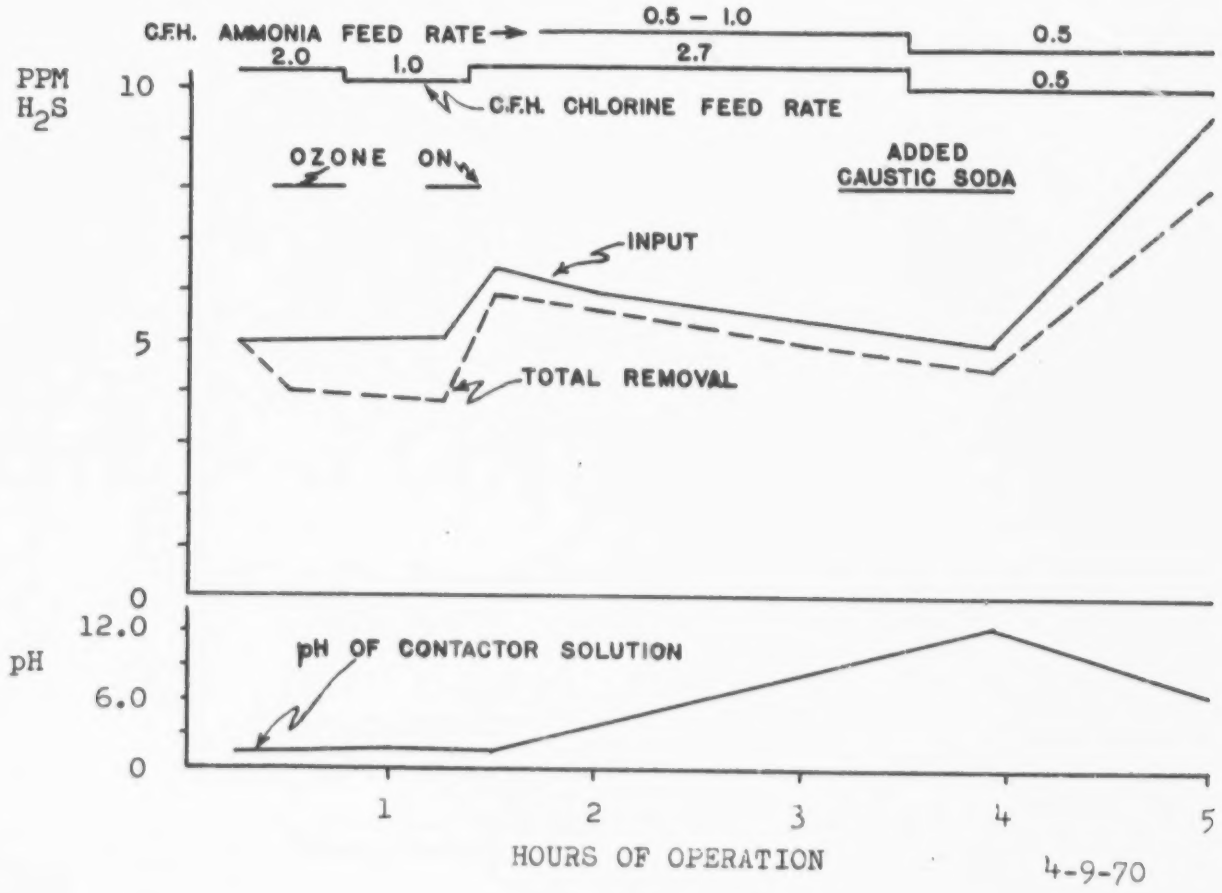


FIG. #33

TABLE #25

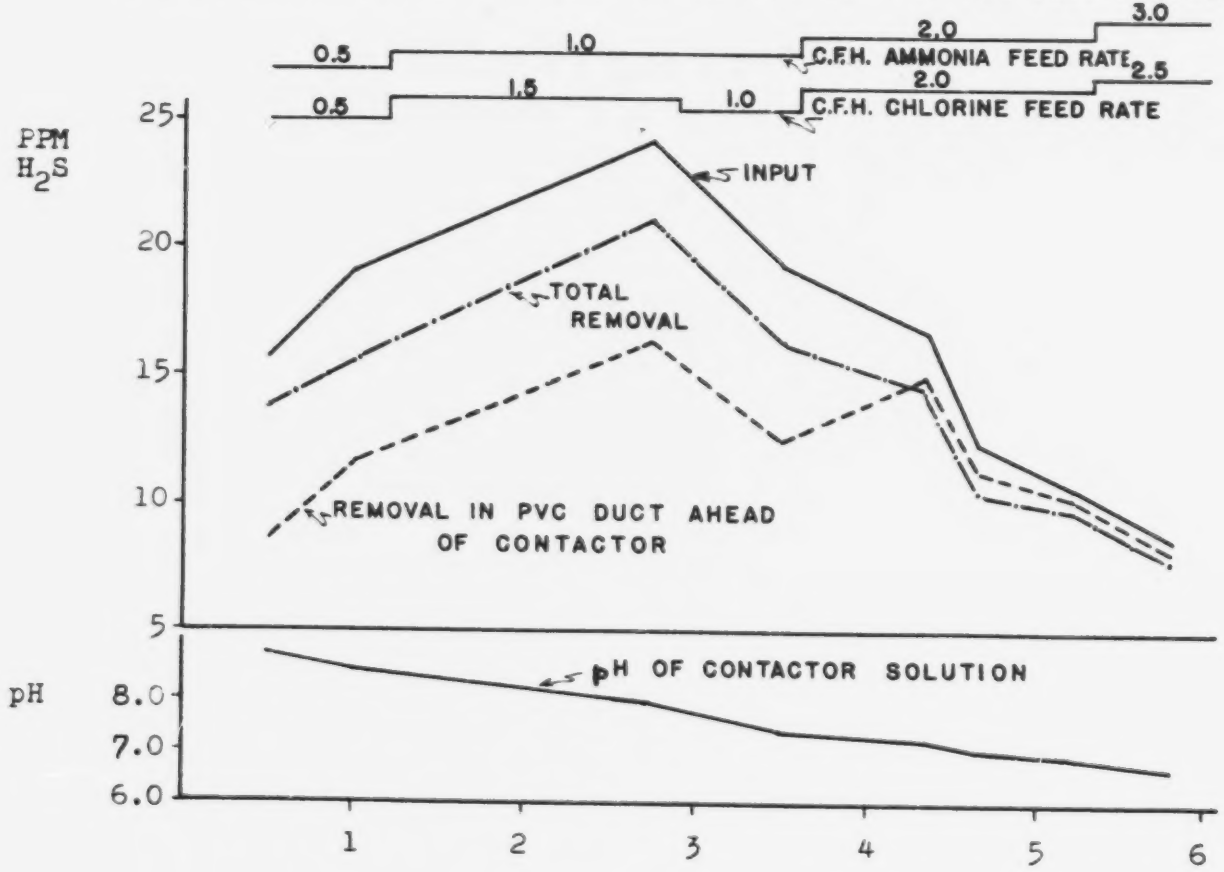
H_2S REMOVAL WITH COPPER–AMMONIUM COMPLEX, CHLORINE GAS AND AMMONIA INJECTION. STATIC AND DYNAMIC CONDITIONS.

DATE	FOUL AIR FLOW CFM	AIR RESI-DENCE TIME SECONDS	CHLORINE GAS INJECTED INTO FOUL AIR CFH	AMMONIA GAS INJECTED INTO CHLORINE TREATED AIR CFH	HYDROGEN SULFIDE INPUT P_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN	pH START	pH END	REMARKS
STATIC CONDITIONS – AMMONIA GAS FEED TO FOUL AIR											
4-13-70	700	3.8	0.0	0.0	8.4	4.0	47.0	30	10.9	10.85	Copper-Ammonium Fresh Solution
	700	3.8	0.0	0.5	13.1	4.2	32.0	30	10.85	10.75	
	700	3.8	0.0	6.0	14.0	5.9	45.0	10	10.75	10.75	
4-14-70	700	3.8	0.0	0.0	6.1	2.3	38.0	30	10.55	10.45	1-day old solution
	700	3.8	0.0	2.0	5.9	4.5	76.0	30	10.45	10.45	
	700	3.8	0.0	6.0	5.7	4.5	79.0	30	10.45	10.30	
	700	3.8	0.5	0.5	9.2	4.9	53.0	30	10.30	10.20	
	700	3.8	2.0	0.5	8.9	8.2	92.0	20	10.20	9.95	
4-15-70	750	3.5	0.0	0.0	12.2	3.6	29.5	15	9.95	9.75	2-day old solution
	700	3.8	2.0	0.5	8.8	7.6	86.5	30	9.75	9.1	
4-20-70	700	3.8	0.5	0.5	17.2	14.4	84.0	30	9.1	8.9	8-day old solution. 5 sprays in contactor
	700	3.8	1.5	1.0	24.2	21.0	87.0	90	8.9	7.9	
	700	3.8	1.0	1.0	19.0	16.1	85.0	60	7.9	7.35	
	700	3.8	2.0	2.0	16.2	14.5	89.5	30	7.35	7.15	
	700	3.8	2.0	2.0	12.6	11.3	89.2	45	7.15	6.75	
	700	3.8	2.5	3.0	7.7	7.1	92.3	30	6.75	6.65	
DYNAMIC CONDITIONS – AMMONIA GAS FEED TO TANK SOLUTION											
4-21-70	700	3.8	0.5	0.5	13.5	13.1	97.0	70	8.25	8.15	
	700	3.8	1.0	1.0	7.6	7.3	96.0	90	8.15	7.55	
	700	3.8	2.0	2.0	6.6	6.1	92.0	80	7.55	4.50	
	700	3.8	2.0	2.0	6.6	6.1	92.0	80	7.55	4.55	
4-22-70	700	3.8	2.0	2.0	11.3	9.8	87.0	30	4.5	6.3	

NOTES: Static conditions: No disc rotation. Solution recirculation on.
Dynamic conditions: Disc rotation. Contact area = 18,800 FT^2/Min.
Total solution volume: 40 gal. (30 gal. in contactor).

Overall input foul air temperature range was 20.0° C to 23.2° C (68.0° F to 73.8° F).
Average Per Cent Relative Humidity (% R.H.): Contactor input 78%, contactor output 78% (4-14-70). 4-20-/4-21-70 Contactor input 75%, Contactor output 92%.

H_2S REMOVAL WITH AN 8-DAY OLD 0.04 M COPPER AMMONIUM COMPLEX SOLUTION, PLUS CHLORINE GAS INJECTED INTO 700 C.F.M. FOUL AIR AND AMMONIA GAS TO REMOVE EXCESS CHLORINE - CONTACT AREA: 18,800 FT^2/MIN. 40 GAL. RECIRCULATED SOLUTION IN THE SYSTEM - NO PVC DISC ROTATION



4-20-70

FIG. #34

H_2S REMOVAL WITH A 9-DAY OLD 0.04 M COPPER AMMONIUM COMPLEX SOLUTION, PLUS CHLORINE GAS INJECTED INTO 700 C.F.M. FOUL AIR AND AMMONIA GAS BUBBLED INTO SOLUTION IN HOLDING TANK
40 GAL. RECIRCULATED SOLUTION IN THE SYSTEM

CONTACT AREA: 18,800 FT^2/MIN.

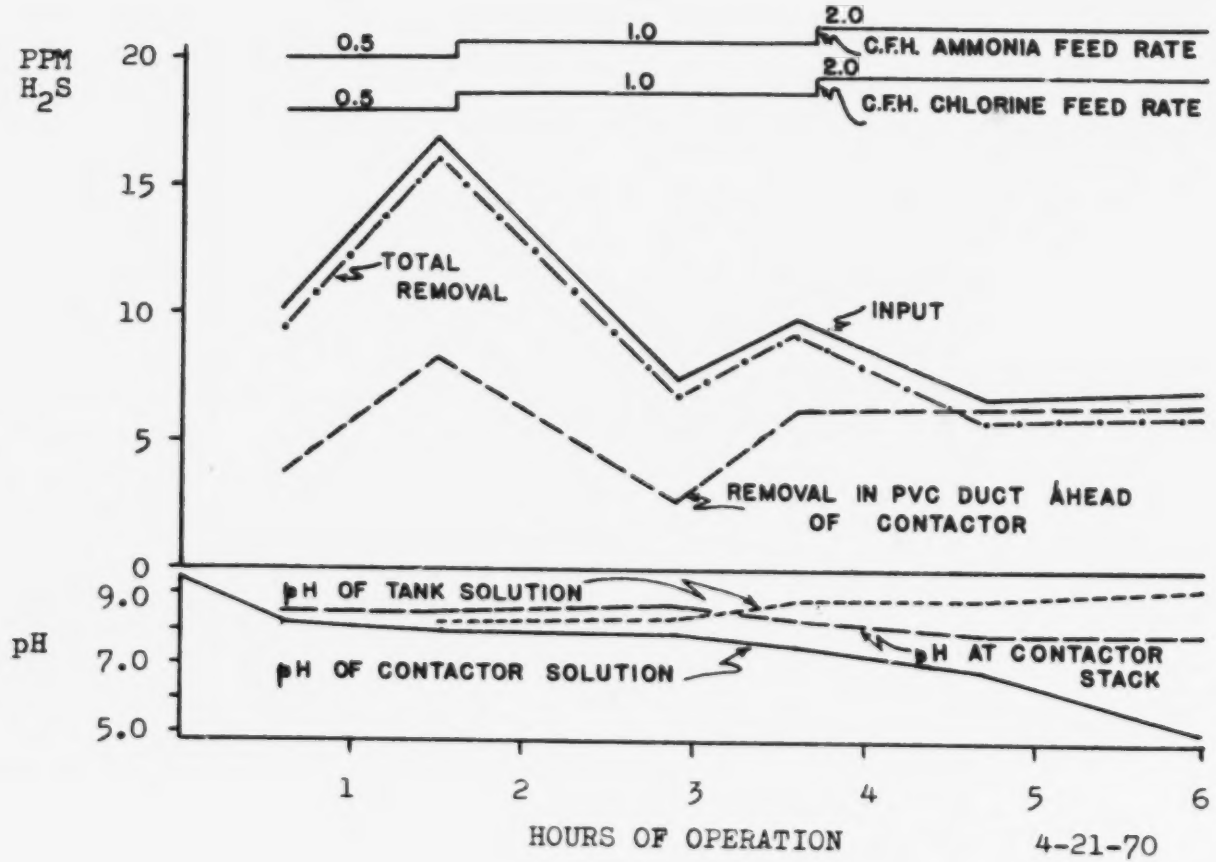


FIG. #35

COPPER-AMMONIUM COMPLEX, CHLORINE & AMMONIA GAS INJECTION

A 0.04 M copper sulfate tap water solution was adjusted to pH=10.9 with concentrated ammonium hydroxide, and its H_2S removal capacities investigated when used in conjunction with chlorine gas and ammonia gas injection. Run conditions were both static and dynamic, maintaining the foul air flow at 700 C.F.M. At low chlorine feed rates of 0.5 and 1.0 CFH, H_2S removal by chlorine action accounts for 60% of total sulfide removal. The reacting solution and ammonia gas injection account for 40% of total sulfide removal. Observed input H_2S range then was 5.0 - 15.0 ppm. These basic observations took place at both static and dynamic conditions. See Table #25, Fig. #34 and #35. However, when dynamic conditions were experimented with, the solution was nearly spent in active copper ion. What was left was copper sulfide as additional contact area for chlorine and ammonia action over remaining H_2S. At low chlorine feed rates (0.5 CFH), the contactor discharged air had fair odor. At higher chlorine feed rates, discharged air odor was chlorine-like, with a profusion of ammonium chloride fumes at contactor stack.

MORPHOLINE AND M-PYROL

Morpholine and M-Pyrol are basic organic solvents in which sulfur compounds have high solubility. Their capabilities were investigated in the hopes of high sulfide removal when used as secondary treatment, with reactant recovery. Good H_2S removal was observed with morpholine at high concentrations. See Table #26.

Immediate losses of Morpholine were noted; morpholine is very volatile and losses are due to its high vapor pressure at ambient temperature. No H_2S removal with M-Pyrol.
See Table #27.

PROPERTIES:

Morpholine:

Colorless, mobile, hygroscopic liquid. Characteristic amine odor - volatile with steam.

Does not form an azeotrope with water.

Boiling point at 760 mm pressure = 128.9°C.

Density: 0.998 (25°C/25°C)

Strong Base pKb = 9.61

10% Morpholine solution: Has damaging action upon PVC and probably other kinds of plastics and equipment.

M-Pyrol:

Almost colorless liquid with mild amine-like odor, hygroscopic.

Boiling point = 202°C (395.6°F)

Flash point = 95°C (204°F)

Dipole moment 4.09

Vapor Pressure = 10 mm Hg at 77°C

Specific gravity (d_4^{25}) = 1.027

A base.

10% Pyrol: Very damaging action upon PVC and probably other kinds of plastics and equipment.

TABLE #26

TAP WATER MORPHOLINE DILUTIONS
WERE MADE IN VARIED CONCENTRATIONS: 0.1%, 1.0%, 5.0%, 10.0%
VOLUME IN CONTACTOR: 25–30 gal., UNDER RECIRCULATION
CONTACT AREA: 15,000 FT^2/MIN. (16 DISCS AT 65 RPM)
1,000 C.F.M. FOUL AIR

DATE	MORPHOLINE CONCENTRATION	AIR RESIDENCE TIME SEC.	LENGTH OF RUN MIN.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %
12-17-69	0.1%	2.7	120 min.	34.0	0.0	0.0
12-22-69	1.0%	3.0	30 min.	14.0	0.0	0.0
12-22-69	NOTE: 15 Gal. solution, no recirculation and 900 CFM foul air.					
12-23-69	1.0%	2.7	90 min.	26.0	1.8	7.0
12-23-69	NOTE: Making-up Morpholine Volume					
12-24-69	5.0%	2.7	30 min.	35.4	1.1	3.0
12-26-69	10.0%	2.7	60 min.	19.9	6.0	30.0
12-26-69	NOTE: 99.5% Removal during first minute of operation.					
1-5-70	10.0%	2.7	30 min.	2.1	1.3	61.0
2-6-70	10.0%	2.7	60 min.	16.2	5.5	34.0
2-6-70	NOTE: Making-up Morpholine Volume.					

There were large morpholine losses through evaporation to the atmosphere.

The 10% morpholine solution showed 100% H_2S removal during the first minute of the run. Input H_2S was then 2.00 PPM.

NOTE: Overall input foul air temperature range was 16.7° C to 20.6° C (62.0° F to 69.0° F).
Average Per Cent Relative Humidity (% R.H.): Contactor input 88%, Contactor discharge 94%.

TABLE # 27

TAP WATER M–PYROL DILUTIONS WERE MADE AT CONCENTRATIONS OF 1% and 2%

VOLUME IN CONTACTOR: 20 – 25 GAL.

CONTACT AREA: 15,000 FT^2/MIN.

1,000 C.F.M. FOUL AIR

DATE	M–PYROL CONCENTRATION	AIR RESIDENCE TIME SECONDS	LENGTH OF RUN MINUTES	INPUT H_2S PPM	H_2S REMOVED PPM	REMOVED %
2-2-70	1%	2.7	15	8.5	NO REMOVAL	
	UNDER RECIRCULATION					
2-4-70	2%	2.7	15	12.5	NO REMOVAL	
	NO RECIRCULATION					

NOTES: Overall input foul air temperature range was 15.9° C to 20.2° C (60.4° F to 68.3° F)

Average Per Cent Relative Humidity (% R.H.): Contactor input 76%, Contactor discharge 96%

AMMONIA GAS

Hydrogen Sulfide removal was investigated while injecting ammonia gas into the foul air stream at a point several feet upstream from contactor. Tap water alone was placed in the contactor.

H_2S removal was fair and somewhat inconsistent. See Table #28 and Fig. #36.

The use of Ozone in conjunction with ammonia did not improve H_2S removal. The odor of discharged air was difficult to evaluate due to interference by ammonia however, it was found to be slightly foul in most instances.

The addition of Cobalt Sulfate is definitely beneficial during the first 15 to 30 minutes. See Table #24, 3-17-70.

CHLORINE GAS

Chlorine is a strong oxidizing agent and was left to test during the latter part of the investigation due to a feeling that rapid corrosion of the equipment could result from its usage. A flow meter capable of measuring 1-4 cubic feet per hour was used to monitor the chlorine gas, which was fed into the foul air duct at a point approximately 20 feet ahead of the two phase contactor.

Tap water was placed in the contactor and sulfide levels monitored under static (no operation of discs in contactor) and dynamic (disc revolving) conditions. An excess of chlorine was noted at once, by odor and by ammonia hydroxide test monitoring.

Since chlorine is a fast reactant, most of the H_2S removal takes place in the duct ahead of contactor, with little removal noted in the two phase contactor. The tap water in the contactor did not seem to do a good job of either completing the H_2S removal, or washing off excess chlorine from exhausted air. See Tables #29, #30 and #31. See Fig. #37, #38 and #39.

See reference 16 in Bibliography.

TABLE #28

H_2S REMOVAL WITH AMMONIA GAS INJECTED TO FOUL AIR
TAP WATER IN CONTACTOR, UNDER RECIRCULATION
700 CFM TO 1,000 CFM FOUL AIR

DATE	AMMONIA GAS INJECTED FOUL TO AIR CFH	CONTACT AREA FT^2/MIN	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
3-13-70	1.0	15,000	14.2	4.0	26.0	45	8.45	8.75	SUSPECT AMMONIA DEMAND BY CONTACTOR RESIDUES
3-13-70	1.0	15,000	7.2	3.6	50.0	20	8.75	8.75	
3-13-70	2.0	15,000	6.1	4.2	69.0	20	8.75	9.25	
3-13-70	3.0	15,000	8.0	5.8	74.0	20	9.25	9.35	
3-13-70	4.0	15,000	4.3	2.4	56.0	20	9.35	9.35	
3-16-70	4.0	18,800	10.7	5.5	52.0	300	8.2	9.05	
3-17-70	4.0	18,800	10.7	5.2	49.0	75	8.2	9.2	
3-17-70	3.0	18,800	11.8	2.7	23.2	240	9.35	9.1	1,000 PPM SODIUM CARBONATE ADDED TO INCREASE & HOLD pH
3-17-70	4.0	18,800	9.9	5.9	41.0	50	9.2	9.2	ADDED 5 GAL. WATER TO MAINTAIN VOLUME
3-17-70	4.0	18,800	14.9	11.7	85.0	15	9.2	9.15	SOME CRYSTALS OF COBALT SULFATE ADDED
3-18-70	4.0	18,800	19.0	9.7	51.0	75	9.15	9.0	RE-RUN YESTERDAY'S COBALT SULFATE SOLUTION

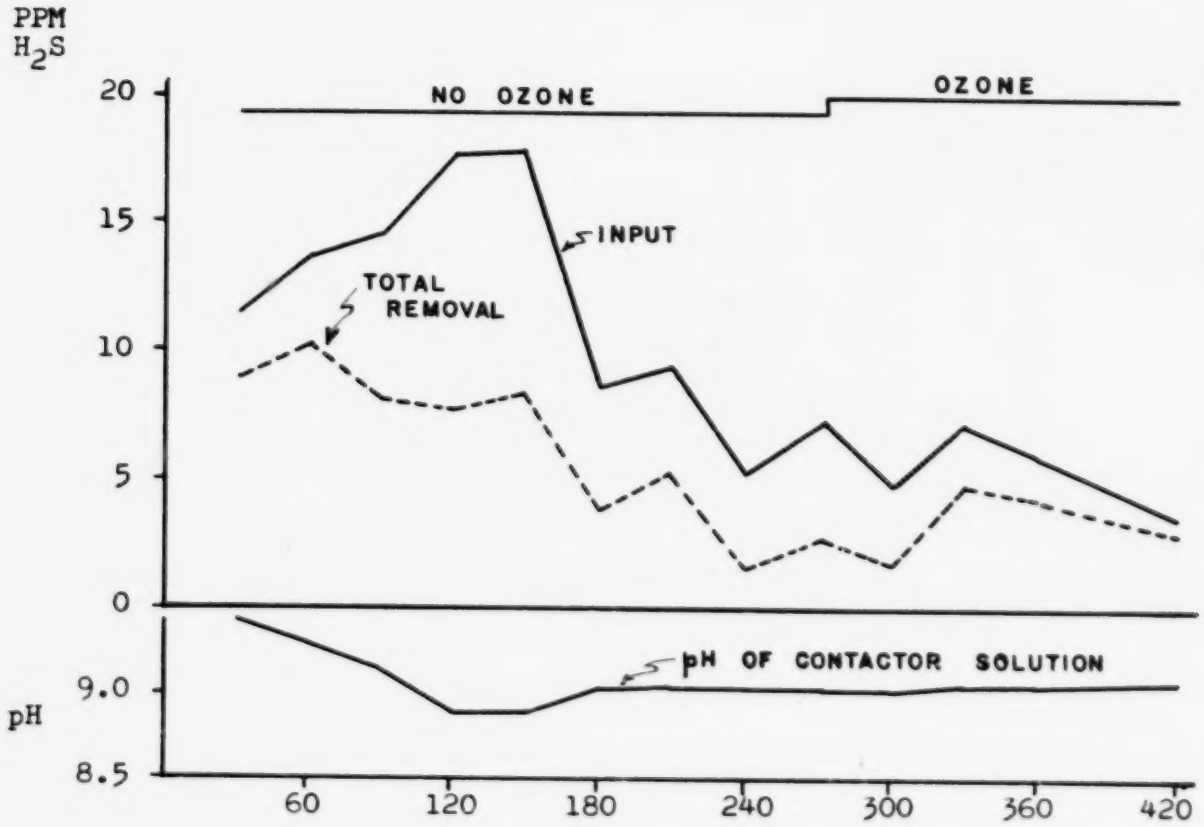
NOTES: TOTAL WATER VOLUME: 30 Gal. ON 3-17-70, 3-16-70
40 Gal. ON 3-17-70, 3-18-70

AIR RESIDENCE TIME: 2.8 SECONDS ON 3-17-70, 2-16-70
2.7 SECONDS ON 3-17-70, 3-18-70

Overall input foul air temperature range was 17.8°C to 22.6°C (64.0° F to 72.6° F).

Average Per Cent Relative Humidity (% R.H.): Input 75%, Contactor discharge 95%

H_2S REMOVAL WITH 4.0 C.F.H. AMMONIA GAS INJECTED INTO 1000 C.F.M. FOUL AIR
30 GAL. RECIRCULATED TAP WATER IN THE SYSTEM
CONTACT AREA: 18,800 FT^2/MIN.



3-16-70

FIG. #36

TABLE #29

H_2S REMOVAL WITH CHLORINE GAS INJECTED TO FOUL AIR AHEAD OF CONTRACTOR

STATIC CONDITIONS.

(CONTACTOR OFF, NO RECIRCULATION)

DATE	FOUL AIR FLOW C.F.M.	AIR RESIDENCE TIME SECONDS	CHLORINE GAS INJECTED TO FOUL AIR C.F.H.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END
4-1-70	900	2.9	0.5	39.0	31.7	81.0	30	5.8	5.7
4-1-70	800	3.3	0.5	21.3	18.9	89.0	60	5.7	5.45
4-1-70	900	2.9	1.0	15.3	13.9	91.0	20	5.45	4.45
4-1-70	900	2.9	2.0	16.8	16.2	96.0	55	4.45	3.40
4-1-70	900	2.9	3.0	13.4	12.3	92.0	45	3.40	3.45
4-1-70	900	2.9	4.0	5.5	5.44	99.0	50	3.45	3.35

35 gallons water in contactor.

o-Tolidine reaction negative. Thiosulfate/starch reaction positive.

Chlorine-like odor at stack.

Most of H_2S removal takes place in duct ahead of contactor, after chlorine injection point.

No Ozone treatment.

Overall input foul air temperature range was 22.0° C to 23.5° C (71.6°F to 74.4° F).

Average Per Cent Relative Humidity (% R.H.). Contactor input 50%, Contactor discharge 56%

H_2S REMOVAL WITH CHLORINE GAS INJECTED INTO 1000 C.F.M. FOUL AIR.
35 GAL. TAP WATER IN THE SYSTEM.
STATIC CONDITIONS.

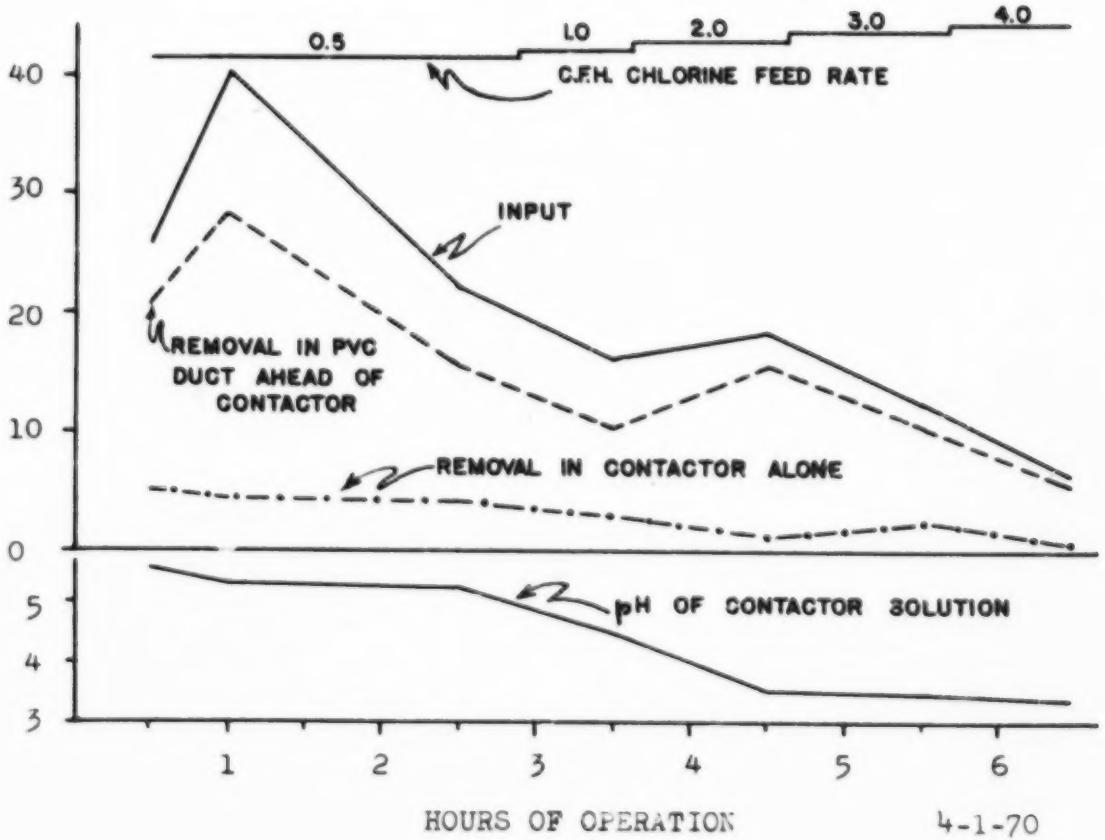


FIG. #37

TABLE #30

H_2S REMOVAL WITH CHLORINE GAS INJECTED INTO FOUL AIR DUCT AT 20 FT. AHEAD OF CONTACTOR

40 GAL. RECIRCULATED TAP WATER IN THE SYSTEM

DATE	FOUL AIR FLOW CFM	AIR RESI DENCE TIME SECONDS	CHLORINE INJECTED TO FOUL AIR CFH	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
3-30-70	1,000	2.7	0.5	19.0	4.6	24.0	60	8.20	7.55	Volume Maintained
	SUSPECT CHLORINE DEMAND BY CONTACTOR RESIDUES?									
3-31-70	1,000	2.7	0.5	16.0	4.3	27.0	360	8.2	1.6	Volume Maintained
	H_2S REMOVAL ERRATIC, BURPING BACK.									
	SUSPECT CHLORINE DEMAND BY CONTACTOR RESIDUES?									
4-2-70	1,000	2.7	0.5	26.3	13.7	52.0	60	8.2	1.8	Volume Maintained
	1,000	2.7	1.0	32.5	18.6	57.0	50	1.8	1.7	
	1,000	2.7	2.0	19.0	12.7	67.0	55	1.7	1.45	
	1,000	2.7	3.0	12.1	11.5	95.0	55	1.45	1.25	
	900	3.0	3.0	8.0	7.2	90.0	60	1.25	1.1	
	500	5.3	3.0	5.9	5.8	99.0	65	1.1	1.05	
	500	5.3	3.0	14.0	13.6	97.0	60	1.05	1.05	

o–Tolidine reaction negative. Thiosulfate/Starch reaction positive.
Copper contamination in contactor water = 2600 PPM (grab sample after 5 hrs. operation on 4-2-70) – Neocuproine method.
Attempted chlorine collection by means of impringer and diffuser, with negative results.
H_2S burping back observed in some instances.

4-3-70	500	5.3	2.5	12.9	11.3	87.0	210	8.2	0.9
	500	5.3	2.5	4.9	4.9	100.0	60	0.9	0.85

o–Tolidine reaction negative. Thiosulfate/Starch reaction positive.
Note: Overall input foul air temperature range was 21.6° C to 22.8° C (70.8° F to 73.0° F).
Average Per Cent Relative Humidity (% R.H.): Contactor input 64%, Contactor discharge 93%

H_2S REMOVAL WITH CHLORINE GAS. INJECTED TO 1000 C.F.M. FOUL AIR.
40 GAL. RECIRCULATED TAP WATER IN THE SYSTEM.
CONTACT AREA: 18,800 FT^2/MIN.

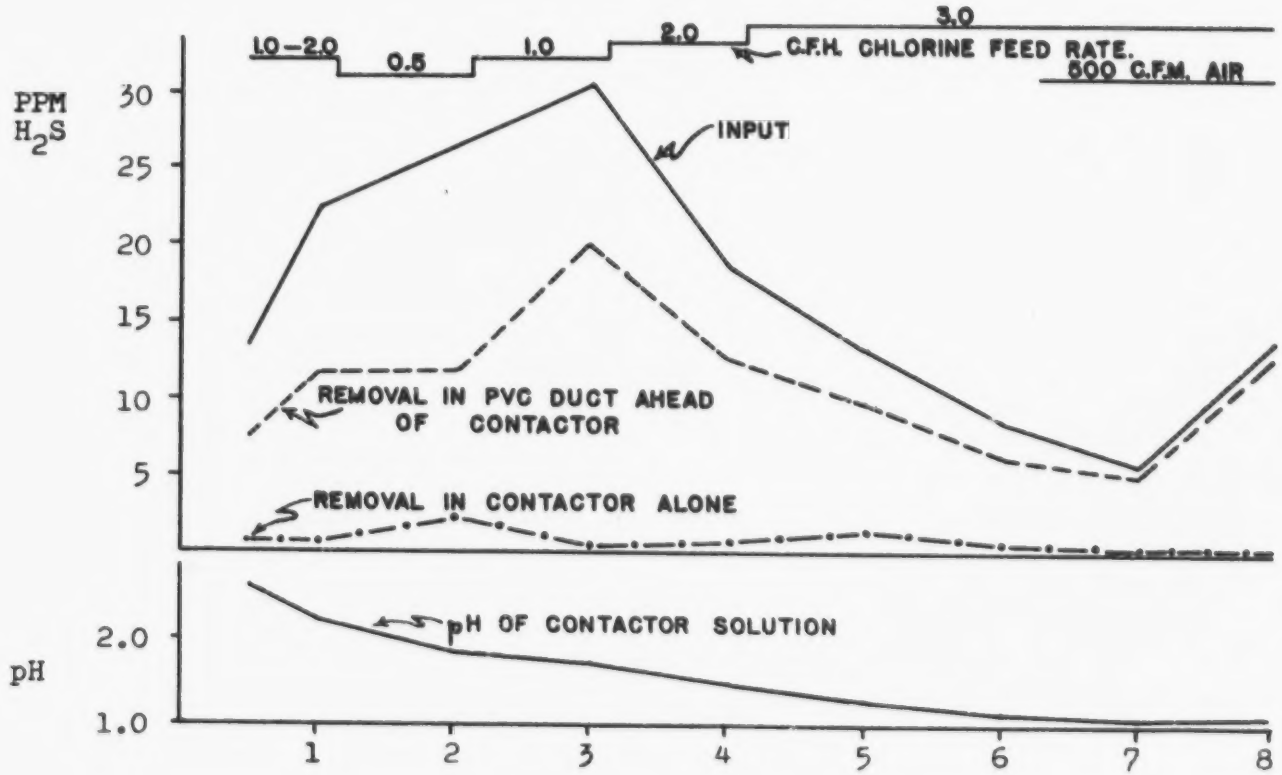


FIG. #38

TABLE #31

H_2S REMOVAL WITH CHLORINE GAS INJECTED INTO FOUL AIR DUCT AT 20FT. AHEAD OF CONTACTOR

30 GAL. TAP WATER IN CONTACTOR, UNDER RECIRCULATION

DATE	FOUL AIR FLOW C.F.M.	AIR RESI-DENCE TIME SECONDS	CHLORINE GAS INTO FOUL AIR C.F.H.	INPUT H_2S PPM	H_2S REMOVED PPM	H_2S REMOVED %	LENGTH OF RUN MIN.	pH START	pH END	REMARKS
4-6-70	1,000	2.7	2.0	10.3	9.6	91.0	75	8.2	8.5	Volume Maintained
	800	3.3	2.0	9.4	8.7	93.0	90	2.85	1.3	
	600	4.5	2.0	4.9	4.9	100.0	70	1.3	1.2	
	1,000	2.7	2.0	9.3	7.6	82.0	50	1.2	1.1	
	900	3.0	2.0	7.6	7.4	98.0	25	1.1	1.1	
	800	3.3	2.0	5.1	4.9	96.0	20	1.1	1.1	
	700	3.8	2.0	5.5	5.5	100.0	15	1.1	1.1	
	600	4.5	2.0	5.5	5.5	100.0	15	1.1	1.1	
	500	5.3	2.0	5.5	5.5	100.0	10	1.1	1.05	

NOTES: Chlorine–like odor at contactor stack.

Contact area = 18,800 Ft^2/min. (20 discs at 65 R.P.M.).

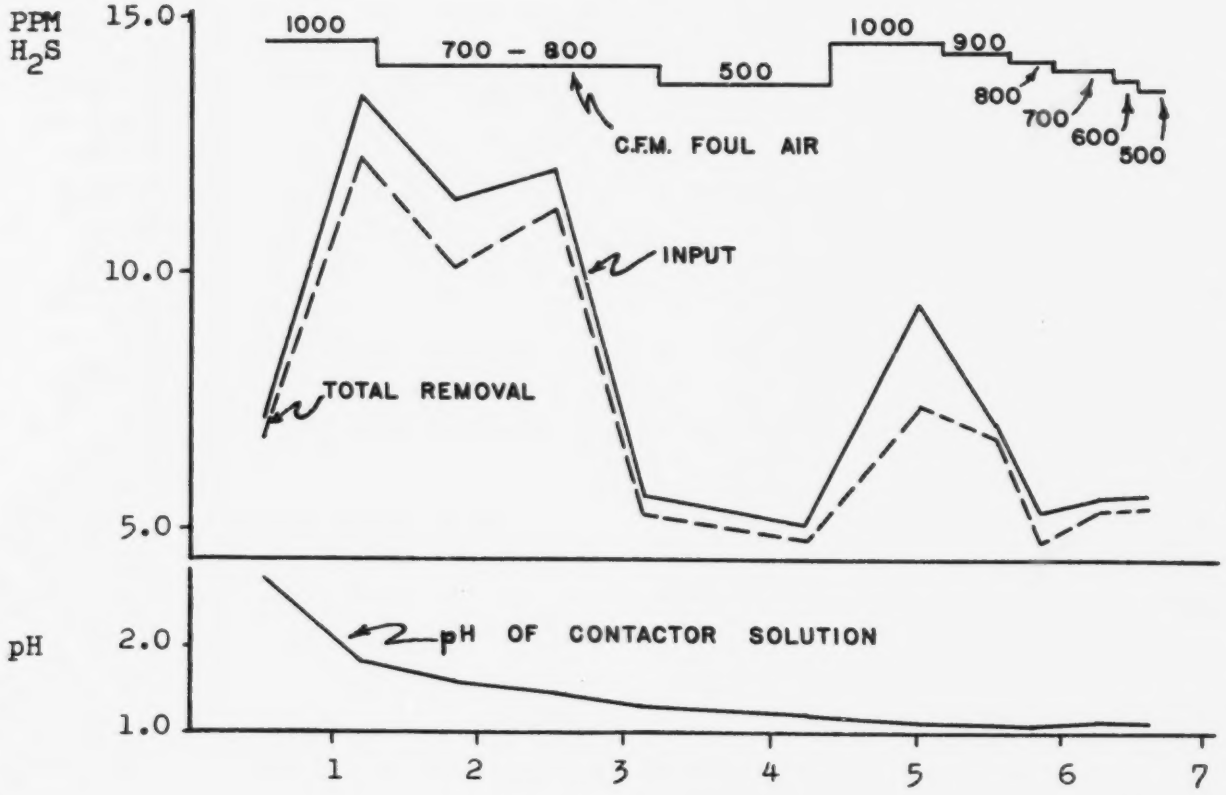
Total volume = 40 gal. tap water (30 gal. in contactor).

No ozone treatment.

Overall input foul air temperature range was 23.6°C to 24.4°C (74.5°F to 76.0°F).

Average Per Cent Relative Humidity (% R.H.): Contactor input 69%, Contactor discharge 97%.

H_2S REMOVAL WITH 2.0 C.F.H. CHLORINE GAS.
40 GALLON RECIRCULATED TAP WATER IN THE SYSTEM
CONTACT AREA: 18,800 FT^2/MIN.



4-6-70

FIG. #39

SECTION 8 - ACKNOWLEDGEMENTS

The help of Ken Morikawa, Assistant Chemist, and other members of the lab personnel, is gratefully acknowledged for laboratory analyses and assistance.

The help of Walter C. Evans, Plant Supervisor, and Leo D. Goggins, Maintenance Foreman; facilitated construction of the two phase contactor.

Thanks is also due to the Operations section whose personnel were often asked to check the odor of discharged air.

The generous loan of Barton Titrators by Robert Austin of ITT Barton Instruments and William F. Garber, Assistant Chief Engineer, Sewage Treatment Division, Bureau of Sanitation, City of Los Angeles, is greatly appreciated.

Thanks is due to Frank F. Wada, Chemist, City of Los Angeles for his generous assistance in setting up the Barton Titrators and his help in the calibration of sulfide detection equipment.

SECTION 9 - BIBLIOGRAPHY

1. Two-phase contactor. Chem. Eng. Vol. 71, #4, p. 80 Feb. 17, 1964.

2. Summer, W., "Methods of Air Deodorization". Elsevier Publishing Co., Inc., New York, N.Y. (1963)

3. Santry, I.W., Jr., "Hydrogen Sulfide Odor Control Measures". Journal Water Pollution Control Federation, 38, 3, 459, (1966).

4. Pomeroy, R., "Hydrogen Sulfide in Sewage". Sewage Works Journal, 13, 3, 498, (1941).

5. Oxidation of Sewage Odors; Austin, Texas. Water and Sewage Works 106: 395-7S 1959.

6. Removal of sewer odors by scrubbing with alkaline solutions. Sewage and Industrial Wastes 30:220-5F 1958.

7. Mass Transfer Operations. Chemical Engineering Series. Treybal. McGraw Hill (1955).

8. Transfer rate. Handbook of Chemical Engineering. J.H. Perry p. 18-45.

9. Nonhebel, G., "Gas Purification Processes". George Newnes Limited, London, England, (1964).

10. Limitations of Lead Acetate Paper. Sanderson. Journal Air Pollution Control Association. 16-328 (1966).

11. Standard Methods - Water and Waste Water. 12th Edition. p. 220 Iodometric method; p. 222 Orthotolidine - Manganese sulfate; p. 223 Orthotolidine - Arsenite.

12. Instrumentation for Hydrogen Sulfide Measurement. William F. Garber, Joe Nagano and Frank F. Wada. Journal Water Pollution Control Federation - Research Supplement, May, 1970. Two parts, Part 2 (Part 1 Journal) p. R 209.

13. Pomeroy, R., "The Determination of Sulfide in Sewage and Sewer Atmospheres." Sewage Works Journal, 13, 3, 502, (1941).

14. Nusbaum I., "Determining Sulfides in Water and Wastewater". Water and Sewage Works, 112, 4, 113, (1965).

15. Repair of Corroded Concrete in a Wastewater treatment Plant. Jack M. Betz. Water Pollution Control Journal. March, 1964, p. 332. (Los Angeles Hyperion Plant.)

16. Nagano, J., "Oxidation of Sulfides During Sewage Chlorination". Sewage and Industrial Wastes Journal, 22, 7, 884, (1950).

17. Kuehner, R.L., and Whipple, H. E. (Editors), "Recent Advances in Odor: Theory, Measurement and Control." Annals of the New York Academy of Sciences, New York 116, 2, 357-746, (1964).

18. Possett, H. S., Reidiers, A. H., "Odor Abatement with Potassium Permanganate Solution." I. and E. C. Product Research and Development, 4, 1, 48, (1965).

19. Summer, W., "Odor Control with Ultraviolet Radiation." Manufacturing Chemist 24, 105-110, (1953).

20. Ewell, A. W., "The Use of Ozone in Cold Storage Plants". Proceeds of the 7th International Congress of Refrigeration. (1936).

21. "Scott's Standard Methods of Chemical Analysis." - 5th Edition. p. 2405 Iodide Method of Schonbein.

22. "Organic Complexing Reagents. Reduced Phenolphthalein." Perrin. p. 262, (1964).

23. "Recommended Methods in Air Pollution Measurements". Air and Industrial Hygiene Laboratory. California State Department of Public Health. Berkeley, California, (1961).

24. Hume, N.B., "Characteristics and effects of Hyperion effluent". W.P.C.F. Journal, 34, 1, 15-35, (1962).

SECTION 10 - GLOSSARY

A.I.S.I. - Methods for hydrogen sulfide determination developed under American Iron and Steel Institute Studies.

ALCONOX - A laboratory detergent, linear alkyl sulfonate, phosphate free.

AZEOTROPES - Any one of two or more compounds which forms mixtures of constant boiling point.

BIZ - Commercial enzyme type detergent.

CAUSTIC SODA - Commercial name for sodium hydroxide, NaOH. Technical grade.

C.F.H. - Cubic feet per hour.

C.F.M. - Cubic feet per minute.

DRAEGER, "SCOTT" - German patented method for field determination of hydrogen sulfide concentrations in air. The methods depend upon passing a measured volume of air through a calibrated vial containing reactive chemicals.

GAL. - Gallon.

H_2S - Hydrogen sulfide: Flammable poisonous gas with characteristic odor of rotten eggs. Adverse level = 0.1 PPM for 1 hour (as per Bay Area Air Pollution Control District, Air Quality Standards). Adverse level definition: Level at which there will be sensory irritation, damage to vegetation, reduction in visibility or similar effects. H_2S occurence: in coal pits, gas wells, sulfur springs, as product of sulfate reduction, decaying organic matter containing sulfur.

I.P.S. CEMENT - Bonding agent for PVC schedule #40 or #80.

E.D.T.A. - See "Versene".

LACCOPEN - A laboratory detergent, linear alkyl sulfonate plus fillers.

LANGELIER INDEX - Predicts the tendency of a water to remove or deposit calcium carbonate (saturation index).

M - MOLAR - Molecular Weight expressed in grams.

mg. - Milligrams.

M.G.D. - Million gallons per day.

O_2 - Oxygen.

O_3 - Ozone.

N - Normal solution. It has one chemical equivalent per liter.

pH - The symbol for the logarithm of the reciprocal of the hydrogen ion concentration in gram equivalents per liter of solution. It is a means of expressing the degree of acidity or basicity of a solution. Thus at normal temperature a neutral solution such as pure distilled water has a pH of about 7.0, a 0.1 N solution of hydrochloric acid has a pH near 1.0 and a 1.0 N solution of sodium hydroxide (strong alkali) has a pH of nearly 14.0.

pK - A measurement of the completeness of an incomplete chemical reaction. It is defined as the negative logarithm (to the base 10) of the equilibrium constant K, for the reaction in question. The pK is most frequently used to express the extent of dissociation or the strength of weak acids and also complex ions, or similar substances. The weaker an electrolyte the larger its pK.

pKb - pK at boiling temperature.

PPM - Parts per million.

PROPRIETARY - Products made and marketed by a person having the exclusive right to manufacture and sell it.

PVC - Polyvinyl chloride $(-H_2CCHC1-)n$. A common and widely used synthetic thermoplastic resin of varying composition.

R.P.M. - Revolutions per minute.

RYZNAR INDEX - Stability index. It is empirical, based on a study of actual operating results with waters of various saturation indexes. Stability index = 2(pHs) - pH. Where pHs = pH at which the water is in equilibrium with calcium carbonate. With waters having a Stability Index of 6.0 or less, scaling increases and the tendency to corrosion decreases. When the stability index is above 7.0, a protective coating of calcium carbonate scale may not be developed. Corrosion would become an increasingly greater problem as the stability index increases above 7.5 or 8.0.

TWO-PHASE CONTACTOR - All plastic (PVC) unit with stainless steel hardware. It consists essentially of a cylindrical shell laid horizontally with a center shaft having perforated discs. A baffle at the 3/4 point divides the lower half into two compartments, the larger serving as a bath sump and the smaller (demister) to remove the mist from the air as it passes through contactor. Various arrangements of drives, orifices, sprays, pumps and orifice-plate meters make this a variable, two-phase liquid gas contactor.

VERSENE - Trademark for sodium salts of E.D.T.A. (ethylene-diamine tetraacetic acid) useful as complexing, chelating, or sequestering agents for hard water salts and other polyvalent metals.